LUT University

Sustainable Design - Biocomposite Materials Database Tool for Use in Engineering Applications

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Mechanical Engineering, Master's Thesis

2025

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Examiners: Professor Juha Varis,

Associate Professor Amir Togiani

Abstract

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81 pages, 34 figures, 0 tables and 2 appendices

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The biocomposite materials database tool for use in engineering applications is a system that utilises a database, form, query and output (DFQO) to offer users the ability to find biocomposite materials that are best suited for their product based on the required mechanical properties for their product. The aim of this system is to offer designers of industrial products and engineering students alike a system to support the design phase of product development.

The DFQO system was created in Microsoft Access after a careful software selection process. It contains 87 materials with 9 selected key mechanical properties as well as non-mechanical properties. The database was populated with a combination of research materials and commercially available materials from NG Nordic Group. The aim of the database's design was to create a system that is fast, functional and intuitive.

The database was tested by group members once populated and in a working state. After in person feedback and surveys from the group were analysed, it was concluded that the creation of the system was a success, with clear avenues of development in the future. The DFQO system will assist with research and development into biocomposite materials.

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Additionally, I would like to thank those who responded to the feedback form.

SYMBOLS AND ABBREVIATIONS

Symbols

G – Giga

K – Kelvin

kg – Kilogram

m – Metre

M – Mega

Pa – Pascals

W – Watt

Abbreviations

ACC – Agricultural Cellulose Composite

ANSYS – Analysis System

BKP – Bleached Kraft Pulp

CAD – Computer Aided Design

CFRP – Carbon Fibre Reinforced Polypropylene

CF – Carbon Fibre

DB – Database

DFMA – Design for Manufacturing and Assembly

DFQO – Design, Form, Query, Output

ERP – Enterprise Resource Planning

GTK – Geologian Tutkimuskeskus

HF – High Function

LAB – Lahti-Lappeenranta University of Applied Sciences

LUT – Lappeenranta-Lahti University of Technology

MA – Manchurian Ash

MS – Microsoft

Nz – Number zero

PA – Polyamide

PALF – Pineapple Leaf Fibre

PHB – Poly(3-Hydroxybutyrate)

PLA – Polylactide

PP – Polypropylene

RAM – Random Access Memory

RAMI – RawMatTERS

SQL – Structured Query Language

SW – SolidWorks

UEF – University of Eastern Finland

UI – User Interface

UP – Unsaturated Polyester

UX – User Experience

VE – Vinyl Ester

VTT – Valtion Teknillinen Tutkimus

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DECLARATIONS

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AI usage

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Responsibility

The author, David Gilmartin, takes full responsibility for the content of this thesis

1. Introduction

The industrial engineering sector is one that is in constant flux, with innovations and streamlining consistently pushing the boundaries of what is possible. In recent decades, a lot of progress has been made in this sector in terms of material research. (Zhang, W. et al. 2022) The later years of the 20th century saw the introduction of composite materials replacing metals and plastics in high performance fields, such as aerospace engineering, military applications and in competitive racing. (Zhang, J. et al. 2022.) At the time, composites were expensive and time-costly materials to produce, and therefore they were not widely used in day-to-day applications. (Armstrong, S. et al. 1984) 40 years on, composites are now used much more widely due to advancements in material production, their wide usage growing as much as 12.5% annually in energy, aerospace, automotive, furniture and shipbuilding industries among others. (Ma, J. et al. 2022.) Wood composites are used in budget furniture to save on costs and to utilise more of the raw material, carbon composites are now a staple of electric vehicle designs, and graphite composites are widely used in a variety of sports equipment - from tennis rackets to field hockey sticks. (Gonzalez, C. et al. 2017)

Composites are often chosen over other materials such as steel, titanium, iron, wood and plastics due to their different, and in certain applications superior, mechanical properties. The benefit in mechanical properties comes at the expense of high production costs and the lack of end-of-life options. The main qualities that composites bring to the table are (He, J. et al. 2022):

- A lighter weight than alternatives.
- A higher strength than alternatives.
- A higher stiffness than alternatives.
- Different insulation properties to alternatives.

It is due to those reasons that composites are popular within high performance applications as previously mentioned, and why development moving forward is crucial.

1.1 Significance of Research

Composite materials are an exciting prospect for the future due to their high-performance capabilities and light weight in comparison to traditional raw-material derived alternatives. (Volpe V. et al. 2019). However, due to the simple structure and variety of unique material elements present in composites, composites are a more difficult material to recycle or reuse than the aforementioned raw materials. (Oliveux, G. et al. 2015) As a result, the circularity of these materials is under scrutiny at a time when a product's life cycle is crucial in reducing waste, raw material usage and energy usage (JEC Composites et al. 2025). While there are ways to recycle and reuse composite materials, these methods are energy-intensive and not cost-efficient in comparison to waste disposal (Muelander, J. et al. 2022).

One example that has proverbially made headlines in the engineering industry is that of wind turbine blades. Wind turbines are one of the most popular forms of renewable energy, especially in Finland (Suomen Uusiutuvat ry, 2024). Wind power is a large contributor to electricity being widely available in Southern Finland. With time, the wind turbine blades wear out due to the elements and regular wear and tear of continuous use (Mishnaevsky, L. 2022). With the turbine blades wearing out and being unfit for use, they must then be disposed of. Due to them being constructed from carbon fibre, the wind turbine blades cannot be efficiently recycled, leaving them taking up considerable space in landfills. When the blades are broken down, they release carbon fibres which pose a threat to the environment and the human body alike (Hertzberg, T. 2005). The lack of research and development into the recycling of composite materials means that there are many such cases of composite waste that poses a health and environmental risk in landfills worldwide (Krauklis, A.E. et al. 2021).

This is where biocomposites come into play. Bio-composites, or bio-based composites are materials that are created by combining several bio-based materials (Puttegowda, M. 2025). Generally, the content of biocomposites follows the same structure as with most other composites, where a set of fibres is interlinked with, and kept in place by a matrix. In bio-composites, both the matrix and the fibres are natural (Jakob, M. et al. 2022).

They offer an alternative to established composites and other non-renewable materials alike, while providing a wider array of end-of-life options, including disassembly and

decomposition. This makes them more appealing from an environmental and ecological perspective than other composites. (Chatziparaskeva, G. et al. 2022). However, they are still in the early stages of research and development, therefore their mechanical properties don't yet match up to the benchmarks set by non-biocomposite materials (Pokharel, A. et al. 2022). There are many European research projects ongoing that aim to further develop and give visibility of biocomposite materials as an alternative to conventional materials and non-recyclable biocomposites.

One such project is ABiCo in Finland. The ABiCo project is a collaborative material research and development project between several Finnish universities and companies. The universities undertaking the material research are LUT, LAB, UEF, Abo and VTT. The work undertaken by the universities and companies involves research into and testing of biocomposite and advanced composite materials. As a result of the collaborative research, new biocomposite materials and material compositions have been achieved. This is crucial research as it will have an impact on the circularity and thus widespread usage of the materials going forward. The DFQO (Design, Form, Query and Output) database system will play a part in introducing these materials to a wider audience with the aim of increasing their usage in various fields of engineering, as well as storing material information and properties.

1.2 Research Problem

As it stands, biocomposites are mostly used in niche applications in the field of engineering (Zwawi, M. et al. 2021). Research into biocomposites is still at an early stage, as is their development. As with any material advancement or breakthrough, a period of refinement, conceptualisation and marketing is required to introduce biocomposites more widely into engineering (Rajeshkumar, L. et al. 2023). One of the problems preventing biocomposites from being used more often is that of accessibility of information - most designers, engineers and students don't have access to the material properties of most biocomposites at this early stage in their development. The lack of information or difficulty accessing this information proves as a considerable roadblock to their consideration when designing and manufacturing products.

1.3 Research Questions

In order to address the research problem in a cohesive and logical manner, a series of research questions must be posed. Upon review of the problems and goals, these are the three research questions that are proposed to drive the research for this work:

1. How can a materials database tool be created for storing information about and searching for biocomposite materials?
2. Can the database system be used in the design phase of engineering projects in educational and industrial applications?
3. Can the database system increase awareness and improve accessibility of biocomposite materials and their mechanical properties?

1.4 Research Aims and Objectives

The aim of this thesis is to create a database system for biocomposite materials that would support designers in the initial phase of a product's development, both in educational and industrial environments. The system would allow the designers to quickly and easily find material properties for biocomposite materials based on the requirements for their product. The system would include functions to search by the material name and a range of mechanical property values, as well as having full access to the whole database unfiltered. Such a streamlined system would be a useful support tool that would benefit the material provider and the user of the database alike. By taking into account the material properties from an early stage, the designer would then be incentivized to prioritise that material at a later stage of the project.

1.5 Pre-existing Solutions

Before creating a database system for biocomposite materials, research needs to be done into pre-existing material databases and their features. Aalto university has a database for materials used in construction in Finland, called Building-Part Specific Material Inventory

Dataset for Buildings in Finland (Kaasalainen, T. et al. 2023). The database is aimed more towards quantity surveying in construction and the materials used commercially within the Finnish construction industry. The database, though rich in information, lacks the features that are needed for the intended system. As it is effectively an excel sheet, it lacks the more detailed search feature that would be desired for the biocomposite database system. That being said, the accessibility of Aalto's database proved to be useful, being very simple to locate, download and open for public use. Another useful tool to draw comparison to is The European Commission's database of EU bio-based industries (The European Commission, 2025). This tool allows the user to search by country, feedstock, product and other criteria, displaying the results on a series of interactive maps of the EU. The capabilities of this database tool compliment it's wide availability, providing a good example of an effective database. It's worth noting that the EU Bio-based industries database was funded by the EU, which is likely considerably higher funding than the scope of this thesis work.

1.6 Limitations of the Research

The research for this paper was limited to open-source scientific literary works and scientific literary works available at the LUT e-library. Paid works and those locked behind monthly subscriptions were not utilised due to the scope of this thesis. Where possible, works from the last 10 years were utilised, as the field is one that is in constant flux. On a few occasions, older works were utilised to paint a picture of the past, and to give context.

Feedback for the system was limited to members of the ABiCo project, LUT engineering students, engineers and quantity surveyors on the LPP6A construction project, and a few independent engineers in Ireland. Overall, the responses cover six fields of engineering, but with greater reach more reliable results could be achieved. As well as this, with more responses more well-rounded feedback regarding this system could be obtained.

1.7 Outline of Thesis

The first few pages contain the details of the contents of the thesis, the acknowledgements, the abbreviations, the units and the abstract.

The main text of the thesis work begins with the introduction, running through the background research for the topic, the significance of the thesis, the research problem and questions, the aims and objectives of the thesis based on the problems and questions and finally the limitations of the work and the outline.

The methods section details the process of creating the DFQO system. The ideation stage for the system was followed by the selection of the appropriate software based on short testing periods. The advantages and disadvantages of the system were detailed. Next, the layout of the system and its various parts were explained in detail. Images showing the creation of the system and the code behind it were shown. The problems encountered along the way were explained as well as the solutions to the problems. The database population was detailed next - from the initial presentation of the system at the ABiCo workshop in June to the material property procurement from ABiCo members in August 2025. The contents of the feedback form are explained in brief with the questions posed to the responders outlined.

The results section explains the completed system, explaining how it works step by step and how to utilise it properly. Each part of the system – the database, the form, the query and the output are explained and their creation detailed. The two main functions are described. Additionally, the various stages of getting feedback during ABiCo presentations are detailed, including feedback that was verbally received.

The analysis and discussion section contains a review of the responses captured in the feedback form that was sent to relevant parties. The review takes the form of a serious of graphs and charts, each analysed for what they mean in terms of quantitative data. The analysed data is discussed in terms of what it means for the DFQO system, biocomposites and sustainability in design. Comparisons are drawn to previous database, in terms of feature sets, accessibility and contents.

The conclusion section summarizes the thesis work, describing the DFQO system succinctly and running through the feedback stages briefly. The findings of the work are outlined. The research problem and research questions are addressed with the thesis in mind. The theoretical and practical implications of the thesis' findings are described. The limitations are acknowledged, with future research proposed based on the contents of this thesis work and its limitations alike. The thesis' contribution to the field is stated.

The thesis is concluded with the references used throughout the text detailed in the Harvard format in the first appendix, and the second appendix containing the table of materials used in the database.

2. Methods

At the beginning of the thesis work, the thesis topic selection process took place. One of the main themes of the Industrial Design Engineering course in LUT was the topic of sustainability. The university has had many cited scientific literary works that are focused on, or in some way related to sustainability (Ranta, T. et al. 2020), (Pekkanen, T.-L. 2021), (Woszczek, A. et al. 2024). The university has additionally participated in local sustainability initiatives with the public. Sustainability is a prevalent theme in all spheres of engineering in education, therefore it was the starting point for ideation. This was then combined with the information processing skills that the author had learned in their field of work – civil, structural and architectural engineering. After an initial meeting with the LUT industrial design engineering professors, the idea of creating a material property database for biocomposite materials came about. It would serve as a useful tool for both the ABiCo project, and potentially in future developments on the topic of biocomposites.

The first step in the process of implementing a material database system into the design phase of a product's development was the creation of the system to begin with. The system in question would have four parts - The Database, The Form, The Query and The Output (DFQO). The database was set to contain all of the information, the form was to allow users to input the desired material properties into the database, the query was intended to search the database based on what has been put into the form and then result of the search in this case was the output.

2.1 Software Selection

The initial idea behind the system was to have a database with hundreds of materials and 20-30 properties. Upon discussion with members of the ABiCo project, these numbers had to be dialled back. The reason for that was due to the varying degree of information regarding material properties that are available to the public, and the material properties that have become available because of the material development within the scope of the project. With the aim of mainly using local materials and sources (Finland), there is not always information available regarding each desired material property. As well as this, including

20-30 properties would mean having between 40-60 questions in the form, bloating the form and slowing down what is intended to be a streamlined system.

In order to create the system, an appropriate software had to be selected. The first candidates were within the google environment - Sheets, Docs and Forms. This ecosystem benefitted from a clean, user-friendly user interface (UI) but had many drawbacks that would complicate the process. The biggest one was a lack of a conventional “Query” option that would link the database to the form. The Query is a crucial part of the system, and the system cannot function without it. Due to this reason, after little research and testing this ecosystem was set aside.

Next up was Microsoft. Research and testing went into the use of Excel and Word to create a database and a form and to link the two together. While this ecosystem did have capabilities to host the DFQO system, the way that the different software linked together made for an un-intuitive user experience (UX). The system involved the user having to fill out the word form by themselves, then uploading it to the relevant excel sheet. As well as this, the word form had to be embedded with complex code that a) was very difficult to get working and b) was very finicky. Meaning if the form was filled out incorrectly, there was a very high chance of the system not working, leaving the user to either figure out the problem by themselves or to refer back to the system developer for support. In either case, this made for a slow and un-intuitive system, failing to meet the criteria specified in the research goals for the thesis.

The third tested software was MySQL, and this one showed greater potential than the previous two. The entire DFQO system could be created within MySQL, however it required strong coding abilities to get working and to keep working once changes were made. The UI of the software itself is not the most user-friendly, targeted towards seasoned programmers and professionals. A short test run yielded results when a simple database was created through the coding, however further research into a potential replacement had to be done before settling on a software that would be difficult to use. The SQL language was promising though, and the search for the correct system then moved onto more user-friendly software that ran on the language.

Next, time went into finding an appropriate alternative to MySQL. Software such as MariaDB, Oracle SQL Developer, phpMyAdmin and PostgreSQL were all looked into

briefly before attention was cast back to the Microsoft ecosystem. Microsoft Access is a database software within the Microsoft family that incorporates the use of SQL but offers a much better UX for the developer of the DFQO. As an application, it has, in recent years, taken a backseat to the more commonly utilised Microsoft applications, such as Excel, Word and PowerPoint. Despite this, it remains a solid, well-optimised system that fulfils the criteria of this project.

Access offers the developer use of SQL in three formats:

- Live View - As the user would see it. This allows the developer to test the system, review user friendly-ness and make changes based on visual aspects.
- Design View - This is a simplified version of SQL view - it allows the developer to intuitively create the system without having to delve deep into the hard code, at the expense of potential logic errors and looping.
- SQL View - The raw code view, which allows developers who are well versed in Access to create a system unconstrained.

Each view has its benefits and its drawbacks, however the ability to freely switch between the three is what makes this software stand out from the rest.

2.1.1 Ideation

The idea from the start was for the system to be utilised in the field of industrial design engineering and in education alike. In the industry, this system would serve as a tool to support the design phase of a project. It would assist with material selection for a variety of different products, as it includes variables that are useful for more than 1 application. In the design phase of a project, once the target material properties are known, this form can be filled out very simply in order to achieve the desired outputs. The outputs would be generated in descending order in order of costs, as this is most commonly the property that can influence the designer’s choice.

Additionally, the designer would be able to search materials by name, allowing them to see material properties for a specific material that they may be aware of. This would not be the backbone of the system but would serve as an additional part.

For students, this tool can prove useful in the design and material selection phases of a project. Those who may not be as familiar with widely available materials in the industry can use it to serve as a jumping-off-point for material selection, offering them both the materials that fit best and access to a database. They could explore this database to further their knowledge and understanding of various materials and their properties.

2.1.2 Pros and Cons

The DFQO system comes with several key advantages over a standard material selection process:

1. The designer gets easy access to a database that contains materials that are widely available in the industry. In Finland it can be difficult to obtain this information without a quote for how much of the material is needed. The process of getting a quote can just as easily be quick or lengthy depending almost entirely on the people involved from the material provider's side. The DFQO system in this case would save a lot of time for the designer. There are other material databases available in Finland, such as RAWMatTers and Aalto's material database, however these do not contain the material properties for biocomposite materials.

2. The material provider would benefit by having their material properties accessible by a wide array of potential customers. When a customer searches for their desired properties, the materials that are output would then be the ones that the designer considers for the final product. This is favourable for the material provider as there would be more eyes on their product than there would be without the database system.

3. Sorting ease - for the designer, they can sort by a combination of the two material properties. They can filter by as many properties as there are, and in order to sort by two properties, equations have been implemented between any two (and every two)

variables. This advanced system will support the designer and goes beyond what excel and table-based databases have to offer.

4. The system does not exude a heavy load on access and thus is an easy process to run even on outdated hardware. The code is short and simple, with a lack of features bringing about a lack of bloatware. The system therefore does not utilize much RAM on the computer and does not slow down any other applications that may be open simultaneously.

The DFQO system also undoubtedly has its disadvantages, mainly:

1. Material providers may be reluctant to offer up their material properties due to competition with other material providers. If a majority of designers look at the properties and see shortcomings in one company's material but not the other's, at the same price point the better material would be selected 99% of the time.

2. Lack of features compared to more advanced software. Systems such as ANSYS and SolidWorks (SW) contain much more information and have more features than the DFQO system, such as a vast selection of materials and properties. ANSYS allows the designer to structurally model their product, and to complete a structural analysis of the object, at the cost of ease of use, a paywall and the software being heavy on hardware. SolidWorks also gives the user a plethora of materials and properties and allows the user to accurately 3D model the object they are designing, once again at the cost of ease of use, a paywall and being heavy on hardware. ANSYS and SW are very useful, industry-standard-level software that are intended for use post-ideation in the design and manufacturing phases of a product's life cycle.

2.2 DFQO System Creation

With a clear goal for the format of the database system after background research, the next step was the creation of the system. As this tool was being created from scratch, the logical place to start was the database itself.

2.2.1 Database

The Database serves as the backbone of the system. It contains 87 materials and 12 material properties, 9 of which are mechanical properties and the remaining 3 are additional properties. It takes the shape of a table, containing 13 columns and 88 rows that can be added to depending on needs. Adding more materials to the database would not affect the query of the system and therefore would not affect the output.

From a practical standpoint, the Database was the most straightforward to create. By itself, it could have been created in any number of different software and formats. Google Sheets and Excel would be the easiest to use were it not for the form, query and output of the system. MS Access allows the database to be used with the desired features, featuring a more relevant SQL-based code.

The series of material properties selected for the database was decided based on a mixture of factors. First, the product purposes for ABiCo project representatives had to be considered. This was done so that the database could immediately be utilised within the scope of the ABiCo project. The project is done in collaboration with:

- Pihla Oy - window and windowpane manufacturer in Finland. For window insulation, the material's thermal conductivity/resistivity properties have to be considered. In Finland this is crucial, as the difference between internal and external temperatures varies annually from 0 degrees Celsius to 70 degrees Celsius.
- Meyer Turku Oy - ship building company in Turku. For maritime applications, the materials need to be able to handle the elements of the open seas. Therefore, corrosion resistance, tensile strength and shear strength are important for a material to be utilised for this purpose.
- NG Group Nordic Oy – Finland-based company working on material recycling and developments in sustainability. NG supported the ABiCo project with their inputs in material properties for biocomposites. The final 10 materials in the database, along with their material properties, were provided by NG Nordic Group.
- Syklo Biocomposites Oy – Finnish circular design company which offers recycling and sustainable manufacturing solutions to a variety of clients. Syklo were a partner

on the project and provided valuable insight in feedback sessions for the DFQO system.

- Metsä Fibre Oy – Finnish leading manufacturer of wood-based biocomposite materials. Metsä Fibre supported the ABiCo project by providing material data regarding wood-based biocomposite materials. Metsä offered valuable insights in feedback sessions.
- Brightplus Oy – Brightplus is a Finnish materials company that produces bio-based materials and coatings.
- Vaisala Oy – Finnish company that utilises composite materials in a variety of applications throughout the Nordics. Vaisala prioritises sustainability in energy production, such as wind energy.
- Fortum Oy – Leading energy company in Finland, using composite materials in a variety of sustainable energy applications, predominantly hydropower, wind power and nuclear power. Biocomposites can prove to be useful for wind turbines, which are a crucial power source in Finland and on the other hand a polluter of landfills. The material that wind turbines are made from must be resilient to weather and high stress and strain conditions.

Next, it was important to consult the universities that are involved in the project: Abo, LUT, LAB, VTT and UEF. Since they are researching and producing the biocomposites and advanced composites, their input had the potential to dictate the limitations of the material property availability.

The database was populated using exclusively biocomposite materials from several sources. The priority for this prototype of the DFQO system was to utilise biocomposite materials that had details available regarding several material properties, such as density, thermal conductivity, et cetera.

2.2.2 Form

The form is the part of the system where the user inputs their desired values. It takes the shape of a set of questions with answer boxes that the user can enter values into. The user

may also not enter values into boxes, which would exclude those parameters from the search. The form is the outward facing part of the system; therefore its appearance is crucial.

Microsoft Access gives the system creator a lot of options for customisation of the form. The boxes and questions can easily be repositioned and aligned. Colours in the form can be altered, and the background can be changed to any imported image. A button at the end of the form feeds the data entered into the query. Access allows customisation of many elements within the form, which is another benefit to using the software. Each form space was labelled, and the query would use these labels to read data from the database.

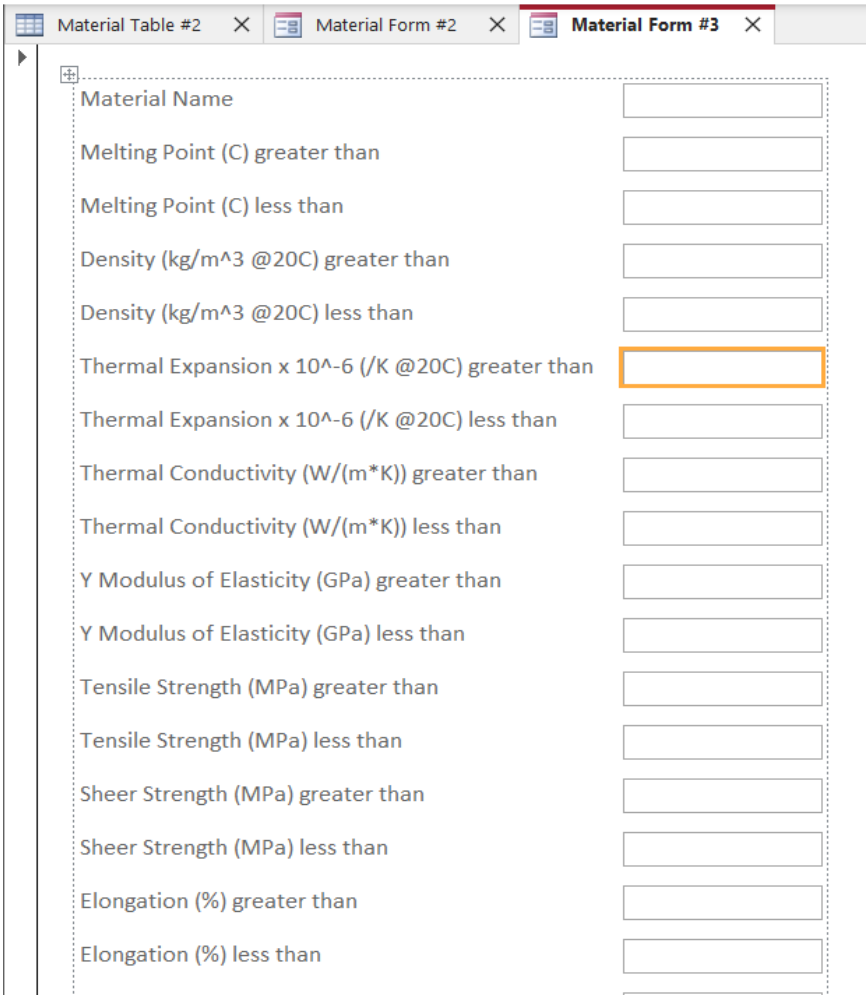

Fig. 1 – Prototype of the layout view for early presentation to ABiCo members, showing the layout plan and response boxes (MS Access).

The form has 3 different views: Layout, Design and Live. Live view is how the user will see the form - this is customized to be user-friendly and simple. The best system is one that you don't notice, so a minimal and streamlined approach was taken for this system. The mock-up of the form for the first ABiCo meeting can be seen above. Notable elements include the presence of LUT's logo, which will be used in conjunction with the ABiCo logo in the final iteration of the form. The widespread presence of light, pleasant and natural colours is also important, as the themes of circularity and sustainability are motivating factors behind both the ABiCo project and this thesis work alike. The form is created in such a way that it is narrow horizontally, in order to fit on the user's monitor without a need for adjustment. This choice was made in order for the form to be comfortably utilized by as many groups as possible, including those who have eyesight troubles and need to have the applications and text in their computer magnified to a great extent.

Below, the design view side box can be seen. The design view contains the various elements of the system, including all of the buttons and text boxes. The elements can be titled in order to then make the SQL code easier to follow. This was used to title the boxes in such a way that they can be identified in the query with ease. Using a shortened titling for the names proved useful in the system, in order to shorten the final code. For example, the text box for "Material Name" was titled "MatNam" as a shortened form.

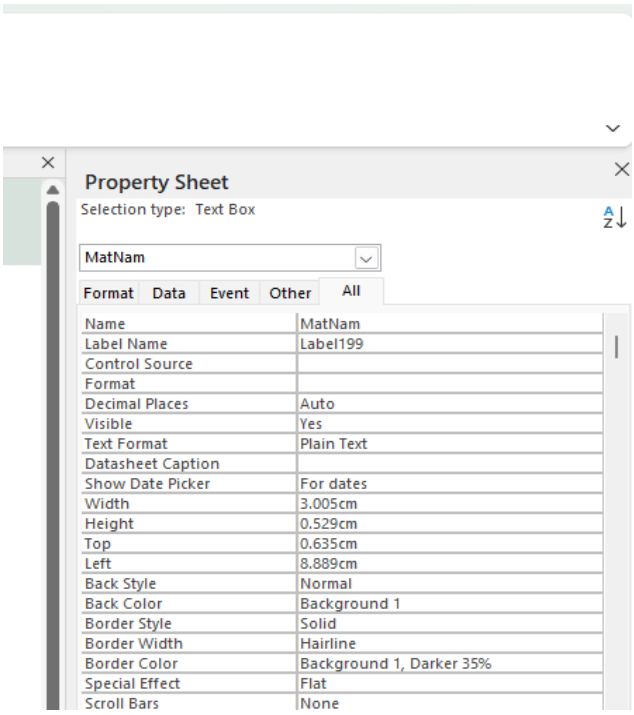

Fig. 2 – Design view showing form element details – the name of a label can be changed here. See MatNam. (MS Access).

Below, the form can be seen in layout view. This view allows the system designer to move certain elements around and organise them on the page. Through this the box sizes, spaces in between boxes and the header of the page were adjusted to include all necessary visual elements. Visual design principles of “Less is More” and “Single Column Layout” were applied here.

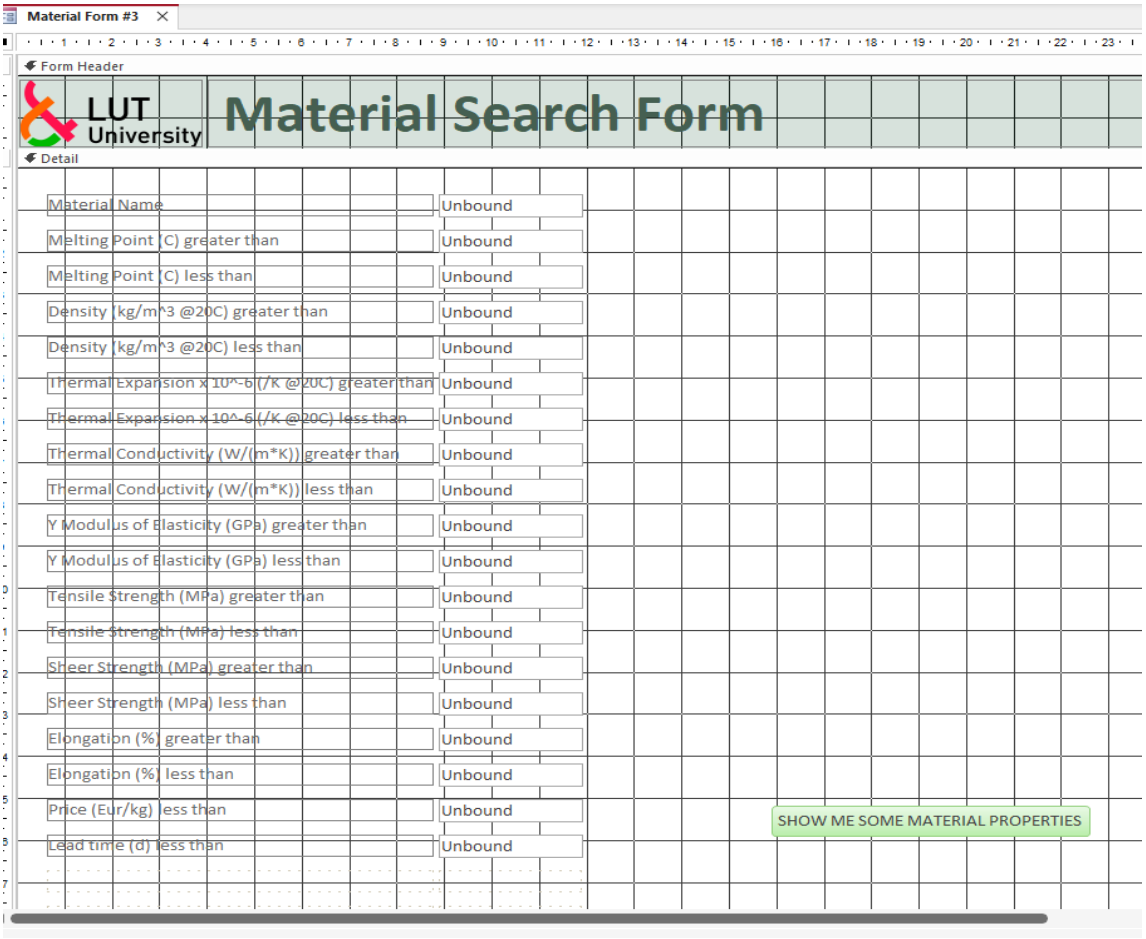

Fig. 3 – Process of designing the form in layout view – sizes, colours, boxes (MS Access).

In the Live view, as the user sees the form, all of the applied principles can be seen (below). The form outlook needed to be tested before settling on a certain look, but the initial perspective was devoid of clutter, simple to navigate and intuitive.

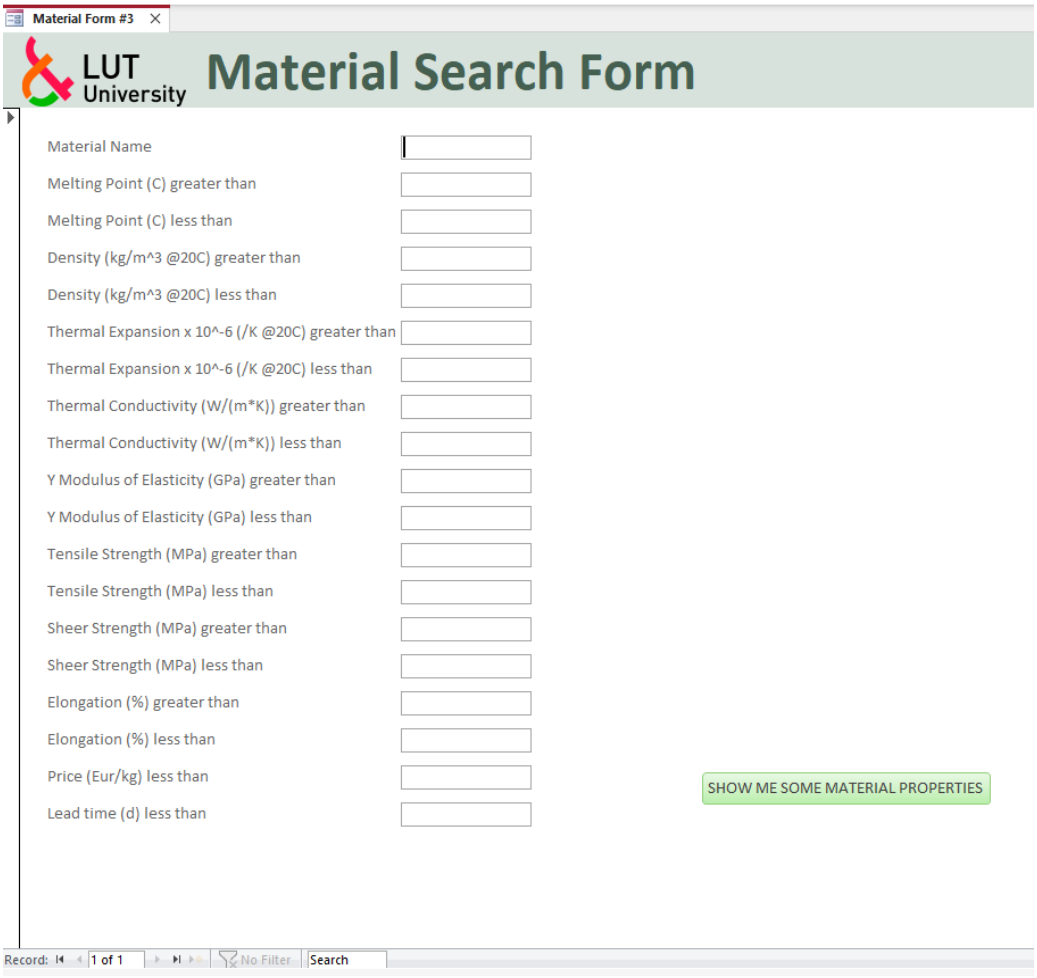

Fig. 4 - Updated live view for periodic presentation to ABiCo members (MS Access).

The final layout can be seen below. It utilizes all of the principles mentioned in regard to the visual design of the form. A mild colour scheme was chosen to not stand out or offend the eyes of the user. The ABiCo logo was included in the form view as part of presenting the system to the ABiCo members. The LUT logo was included as the database was created by a LUT member. The background is grey so that the database is readable in well-lit conditions, and not an eyesore when viewed in a dark space. The text is clear and legible, and the units are included in order to give the scale for the search parameters.

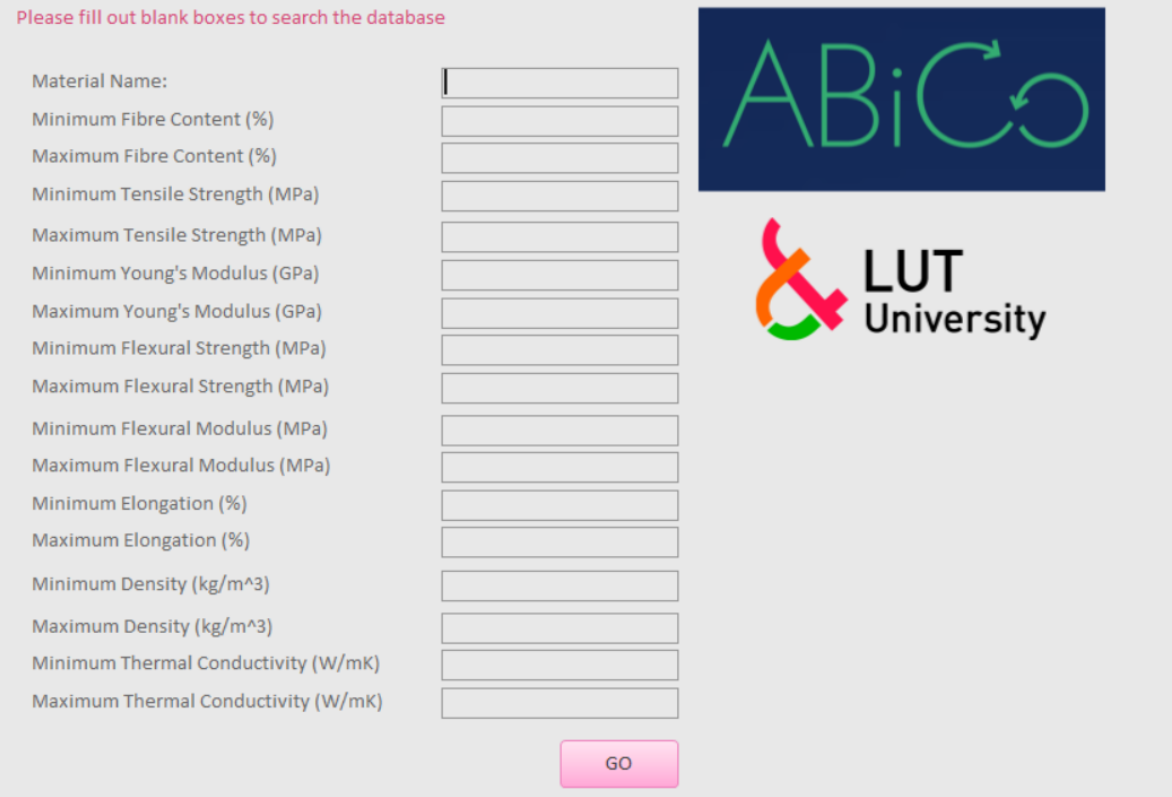

Fig. 5 – Final form view from the user's perspective (MS Access).

2.2.3 Query

The query is the part of the DFQO system that required the most careful selection of application. Many databases and SQL software exist, however very few are user friendly to those who have not used them before. MySQL for example, only contained options to code the system. This is effective if the creator has the knowledge to code within the SQL language. Microsoft Access, on the other hand, allows the user to decide what the query does with greater ease. There is an SQL view that shows the pure code, but crucially, there is also a design view that is far more intuitive to those unfamiliar with the SQL language. Using the design view, the initial stages of the software's design were undertaken for this very reason, however in order to optimise the code and remove looping and therefore reduce RAM usage, the SQL view had to be used in the end.

The Query is where most of the issues were faced. As the designer of the system was previously unfamiliar with the SQL language, many times when an issue arose, the solution to the issue was not immediately clear. Some of the notable issues faced will be explained in more detail in this text in order for future researchers to avoid the mistakes and issues faced as part of related future works and to the creation of a similar system. The second prototype would also serve as the starting point for the final system.

Below, the setup for the Query can be seen. The first step was to include all of the material property fields within the database. These can be seen highlighted as a box in the screenshot below. The screenshot notably shows the design view, with the sheet format at the bottom of the interface serving as the location of parameter entry.

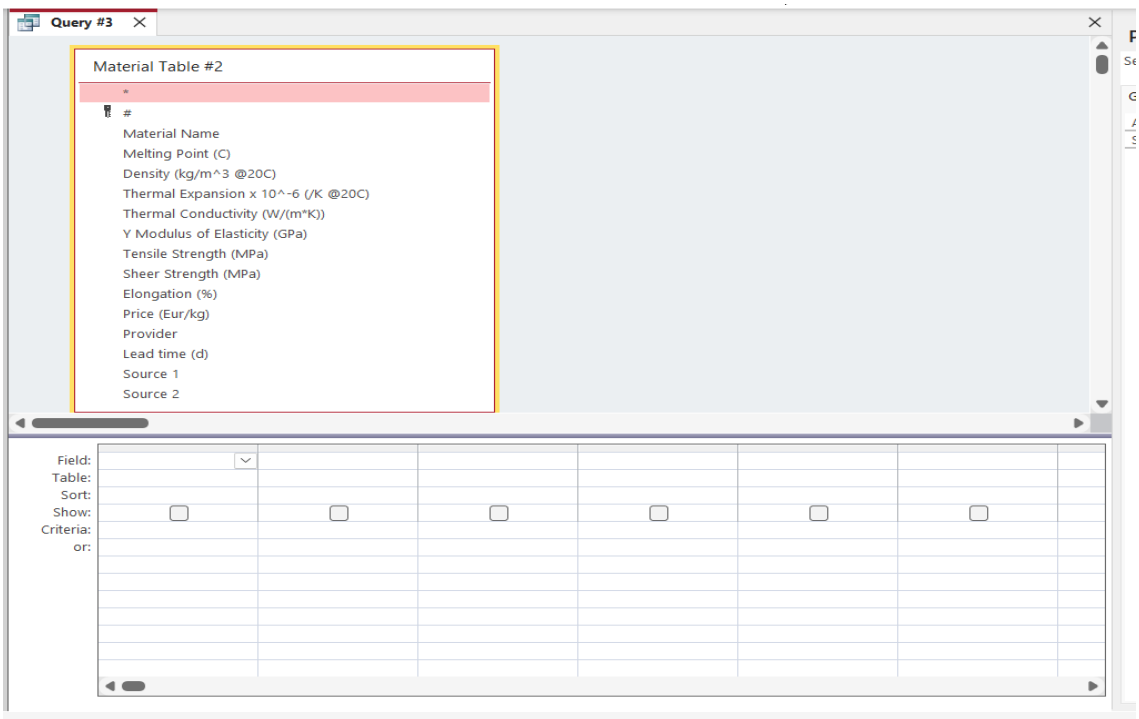

Fig. 6 - Query design view showing import of the database to the query (MS Access).

In the screenshot below, the text can be seen entered. It contains the shortened format text used in the form and in the database alike. To link the database to the query, in one example, the simplified “MelPoi” from the database was linked to “MelPoiGre” in the form using the syntax “IS >=”.

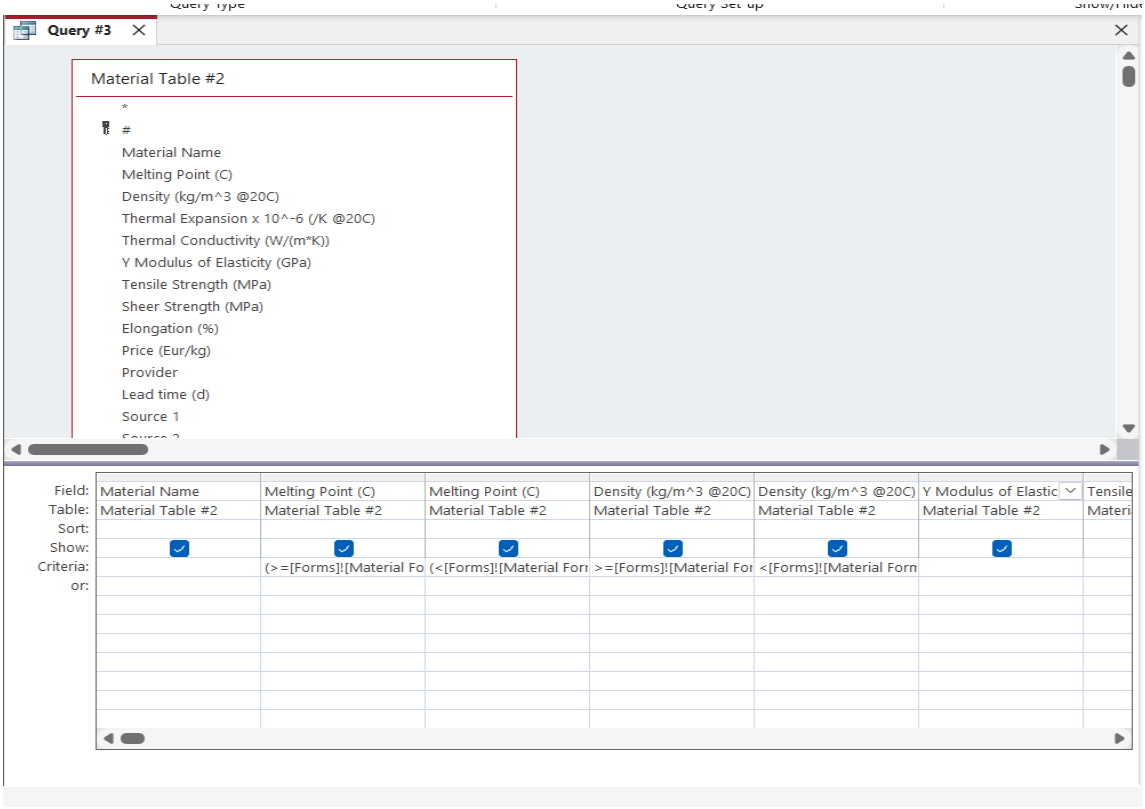

Fig. 7 – Query boxes being populated with code linking the form to the database in early phases of the query's writing (MS Access).

In order to search through the database, the code below had to be utilized. The code uses a "LIKE **user entry***" format, which indicates to the system to search for any material that contains the letters entered by the user. The use of the symbols "*_*" allow for any word that contains some other characters either side of the desired ones. Without their use, the database would only be searched based on those characters exactly.

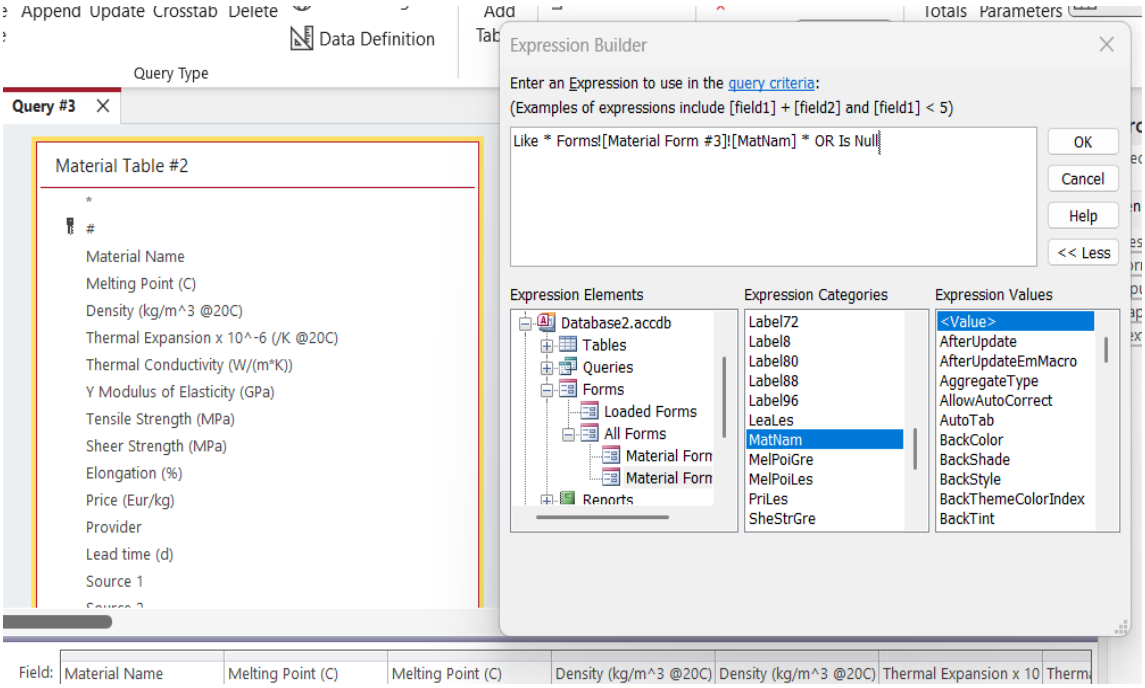

Fig. 8 – Detail of the code linking the database to the form in query design view - Search by name (MS Access).

To link the database to the query, in one example, the simplified “MelPoi” from the database (which is the short-form text for the value “Melting Point”) was linked to “MelPoiGre” in the form using the syntax “IS >=”. The code written down to link the two can be seen below, by using the “wizard” tool in Access, which can be seen as a popup in the centre of the screenshot.

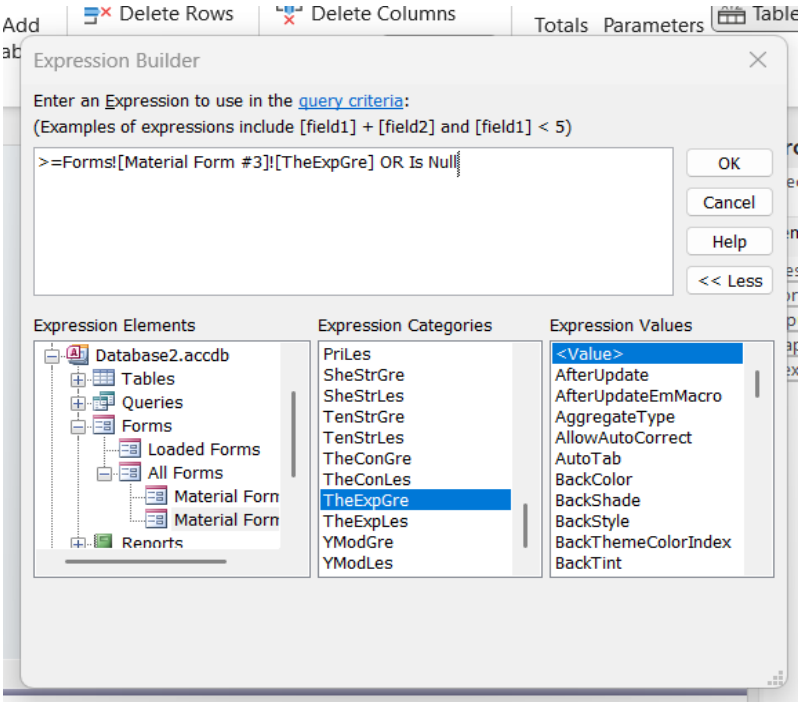

Fig. 9 – Detail of the code linking the database to the form in query design view – Search by property range. Code specifies thermal expansion greater than the value entered into the form, or no search if the form is left empty (MS Access).

The form contained two spaces to fill in target values for certain material properties. These would be “value lower than” and/or “value greater than” in relation to, for example, Elongation %. The first big issue arose when two separate queries were created in relation to a singular column in the database. Thus, the Output did not match the database, and did not show any of the desired materials

In order for the output to match the input, the code had to be altered by combining two function lines into a single line, but it allowed for an input from one of “value greater than” or “value less than”. Below the empty output as a result of a logical error can be seen.

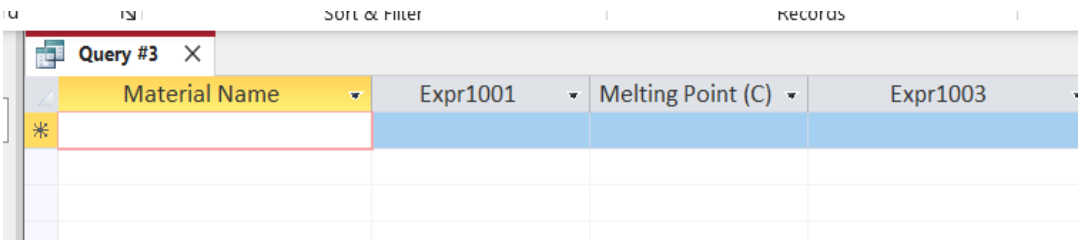

Fig. 10 - No Output Due to Logic Error in Code (MS Access).

The code below caused no outputs to be visible; this was due to the use of the argument "And" between every command. This caused the system to search the database for a material with properties both greater than and less than what the user enters into the form. This creates a flaw in the logic of the code. Additionally, the code below also contains a mistake where one of the [MelPoiGre] arguments should instead be [MelPoiLes], however this is a minor error that can be fixed without redesign.

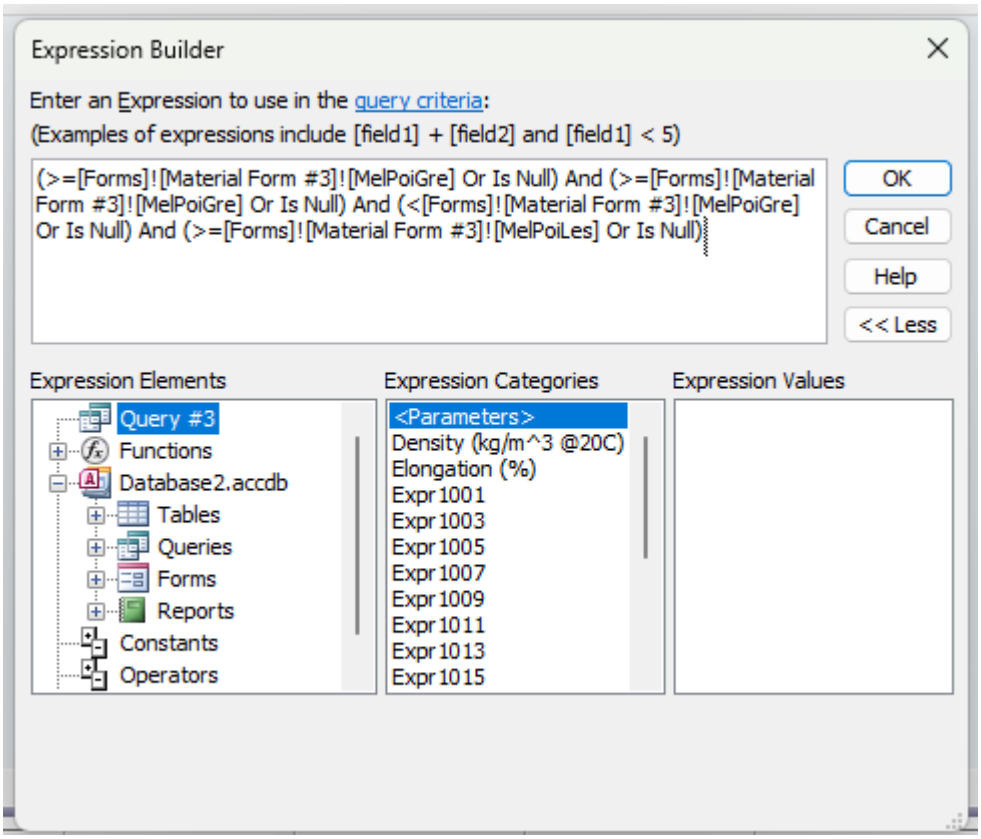

Fig. 11 – Attempted code that resulted in a logic problem. (MS Access).

Below, the solution to the aforementioned problem can be seen, where the “And” arguments have been replaced with “Or” arguments. This creates an issue in itself, which will be described in more detail later in this section.

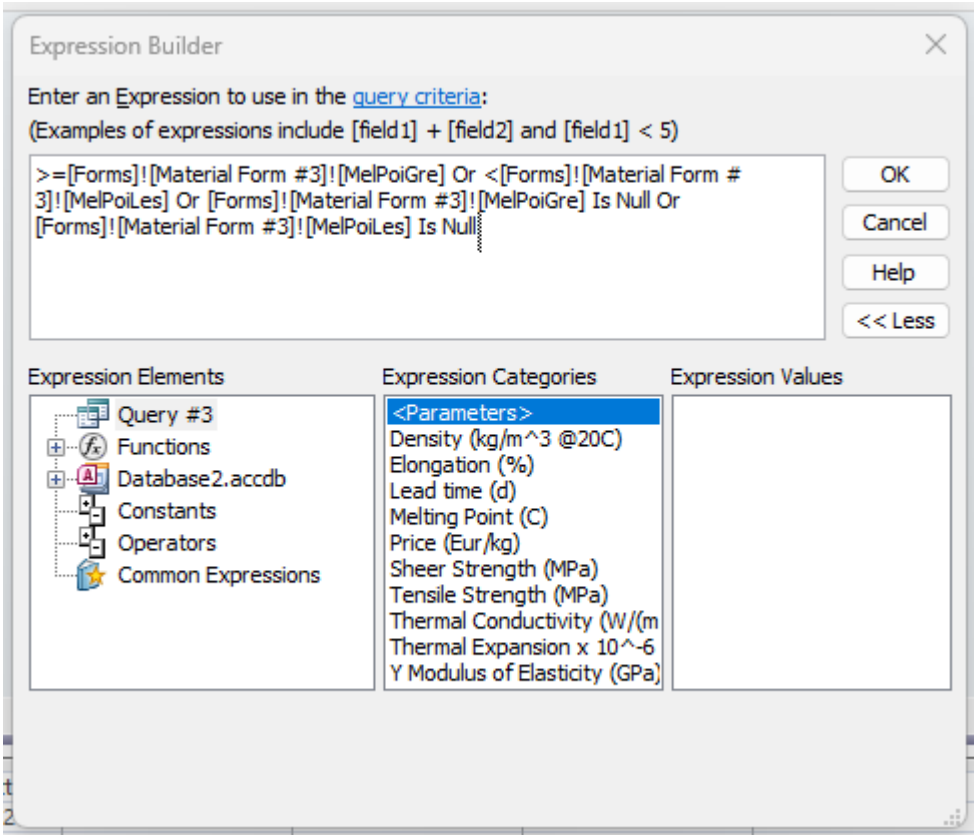

Fig. 12 - Solution to the logic problem, but a new problem arises as the code loops infinitely. (MS Access).

Below, the design view of the code from above can be seen. What immediately stands out is the sheer quantity of lines of code that the system must run. This, however, is just the tip of the iceberg, as the lines of code extend a great deal below what is immediately visible.

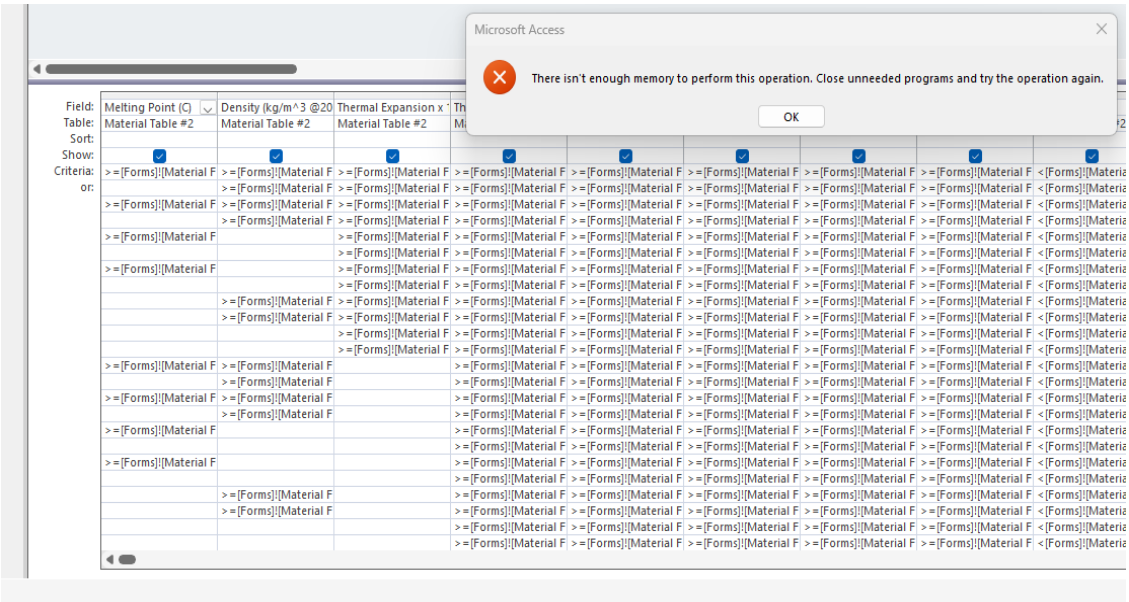

Fig. 13 – How the looping code impacts the boxes in the query. Looping can be seen under the error. (MS Access).

The current code was looping repeatedly, going through each and every option possible before returning the output. This was making the system considerably slower than it needs to be, crashing the application when more than 8 columns were introduced. The crashes were occurring on a 2024 laptop that contains 32GB of RAM, which is more than most notebooks and office-level laptops would have. In order to fulfil the user-friendly requirement, the code had to be considerably simplified. The issue was later fixed by accessing the code through SQL mode. Further research was done into the SQL language in order to find a way to simplify the text, and to remove looping. After more time learning SQL, and several unsuccessful tests, the code was simplified to this:

ABICO QUERY

```
SELECT
   [ABICO WS TEST].[Material Name],
   [ABICO WS TEST].[Melting Point (deg C)],
   [ABICO WS TEST].[Thermal Conductivity (W/(m*K))],
   [ABICO WS TEST].[Thermal Expansion x 10^-6 (/K @20C)],
   [ABICO WS TEST].[Price (Eur/kg)],
   [ABICO WS TEST].[Lead time (d)],
   [ABICO WS TEST].Source
FROM
   [ABICO WS TEST]
WHERE
   ([Forms]![ABICO FORM]![TheExpLes] Is Null OR [ABICO WS TEST].[Thermal Expansion x 10^-6 (/K @20C)] < [Forms]![ABICO FORM]![TheExpLes]) AND
   ([Forms]![ABICO FORM]![MaxPri] Is Null OR [ABICO WS TEST].[Price (Eur/kg)] < [Forms]![ABICO FORM]![MaxPri]) AND
   ([Forms]![ABICO FORM]![MaxLea] Is Null OR [ABICO WS TEST].[Lead time (d)] < [Forms]![ABICO FORM]![MaxLea]) AND
   ([Forms]![ABICO FORM]![MelPoiLes] Is Null OR [ABICO WS TEST].[Melting Point (deg C)] < [Forms]![ABICO FORM]![MelPoiLes]) AND
   ([Forms]![ABICO FORM]![TheConLes] Is Null OR [ABICO WS TEST].[Thermal Conductivity (W/(m*K))] < [Forms]![ABICO FORM]![TheConLes]);
```

Fig. 14 - Logic simplification in SQL to avoid looping.

Instead of going item by item and listing all the possible output conditions, this code broke down the process more logically: take from all of the database columns that fulfils all of the criteria entered into the form. This tremendously reduced the run time for the program, but returned every possible output every time, so it had to be fixed once again for the final version.

2.2.4 Output

The output of the system was used to test the changes made in each step of the system's lifespan. Often, the output not working as intended indicated that a mistake had been made in the query. This took the shape of one of the following:

- no output - meaning the constraints in the query are too strict and don't allow any kind of output. This means the code has to be simplified or syntax has to be fixed. A large logical error could also indicate this.
- all output - meaning the constraints are likely doubled up, allowing all of the database items to be shown regardless of form input.
- outputs some items, but not correctly based on form inputs - meaning there is likely a minor error in specific lines of code, or a logic error between lines.

Eventually, the correct code was selected gave all of the desired outputs. Once the output is displayed and the system has fulfilled its purpose to the user, the user can then simply close the output window to search the database based on another material property.

2.3 Feedback and Changes

In June, an early version of the DFQO system was presented to all present parties at an ABiCo workshop. The presentation started with an introduction to the team working on the system and to the background and motivation for the creation of this system. Each part of the system was explained - the database, the form, the query in more detail and finally the output. After this, the aim of this database was reiterated in a bit more detail before the room was asked for feedback and questions about it.

The DFQO system that was presented at that time was set to contain biocomposite materials in conjunction with composite materials, and common materials used in various fields in engineering. The logic behind that was to have a comparison between biocomposites and other materials used within the industry. One member mentioned the possibility of making the DFQO system entirely based around biocomposites and recycled composites, leaving common industry materials aside, as databases for those already exist. This proposition was taken on board by the LUT team as LUT's work package in the ABiCo project heavily revolved around sustainability of composites. Additionally, this would separate the database from existing material categorisation systems, such as RawMatTERS Finland (RAMI) created by Aalto, VTT and GTK, and Muoviteollisuus ry's directory of composites.

A large portion of the feedback was focused around questioning the necessity of this system, when other existing material databases offer more features than will be available with this database upon completion of the system. The answer to those questions can be summarized in two motivating factors: ease of use and accessibility. Firstly, the majority of database systems are based on old software or pure code, the majority of which has a user interface dating back to the 2000s and early 2010s. Often the software are un-intuitive and complicated, offering a plethora of options to those who understand how to use it, and lacking the simplicity and logical layout that would help those unfamiliar with databases. The DFQO system for this project is largely based around providing a service to designers

who may not have the skills to navigate a complex database system. In this regard, the DFQO system offers a simple form page and a clear output of material properties that can be navigated with little difficulty. And with the simplicity of the code utilised, the system is quick and accurate, allowing the user to navigate it and change criteria in a few clicks. A guideline is included with the system, which will help the users navigate the system.

The next part of the response was accessibility - while other material databases exist in Finland, access to them can only be obtained through working in collaboration with the owners of the database, or through purchasing access to the software and system. This often costs thousands of euros. The DFQO system, in turn, allows parties involved in the ABiCo project to have free and open access to the database, readily available at a moment's notice.

Next, the companies involved in the ABiCo project joined in the presentations to give their feedback. The presentation about the database took a considerable portion of LUT's allotted presentation time due to engagement from the previous day. A more summarised version of the previous day's presentation was given, and a short demo was shown to the room. One company representative mentioned the potential inclusion of dynamic material properties as well as the ones that were shown in the demo. The inclusion of these properties was already in the plan for this system, just not included in that particular early prototype of the system in order to show how the early code worked. Some specific properties were mentioned – Tensile Strength, Young's Modulus and Thermal Conductivity, which were all added to the database later on.

Later in the development of the DFQO system, a working version of the system was completed in mid-September. At this point, the code within the query was working without any function-impacting errors. A minor bug was still present, but it did not affect the overall usability of the system. It was decided that before making the system available to other members of the ABiCo project, it would first be presented to a few key members of the ABiCo project. After this presentation, once all parties were satisfied with the first prototype of the DFQO system, it was ready to be presented to engineers for final feedback.

3. Results

The DFQO system was created from scratch within the MS Access platform. It is comprised of 4 parts – the Database, the Form, the Query and the Output. Below, the working and final prototype of this system within the scope of this thesis is detailed.

3.1 The DFQO System

The DFQO system can be accessed by anyone who receives the link to the google drive on which it is hosted. They are able to download the database but cannot edit the drive itself, in order to prevent tampering. The drive can be found by following this link: https://drive.google.com/drive/u/1/folders/18hLKdwl4qcal_5T_hxnS8qK9nlYsNhSO

The commercially available biocomposite materials were provided to the thesis by a member of NG Nordic Group. The materials are all available on request through the company, and their material properties are listed in the detail sheet.

The research materials were obtained from 3 sources. The first had 7 materials and material properties available and was selected due to its Finnish origin (Uusi-Tarkka, E.-K. et al. 2023). The materials in this scientific literary article were all research materials based on Spinnova and Lyocell. Tensile strength and elongation mechanical properties were included in the database table.

The second source was selected due to its abundance of materials and material properties, with 66 total materials added to the DFQO database (La Gennusa, M. et al. 2017) The 66 materials added to the database included properties on: orientation, matrix, fibre content, Young's modulus, flexural strength and some included flexural modulus, density and thermal conductivity.

The third source was selected due to the materials were all Manchurian-ash-derived, which provided a different side to biocomposites to what is usually studied in the Nordics. (Chen, K. et al. 2020) Additional material properties included tensile strength, elongation, orientation and matrix. The source included 4 material variants of Manchurian ash.

All of the materials and material properties can be seen in more detail in the second appendix at the end of this thesis.

The final query took the form seen below:

```
SELECT [DFQO Mat 1].[ID], [DFQO Mat 1].[Material Name], [DFQO Mat 1].[Orientation], [DFQO Mat 1].[Matrix], [DFQO Mat 1].[Fibre Content (%)], [DFQO Mat 1].[Tensile Strength (MPa)], [DFQO Mat 1].[Young's Modulus (GPa)], [DFQO Mat 1].[Flexural Strength (MPa)], [DFQO Mat 1].[Flexural Modulus (MPa)], [DFQO Mat 1].[Elongation (%)], [DFQO Mat 1].[Density (kg/m^3)], [DFQO Mat 1].[Thermal Conductivity (W/mK)], [DFQO Mat 1].[Link]

FROM [DFQO Mat 1]

WHERE (

    Nz([Forms]![DFQO Form 1]![MatNam], "") = ""

    OR [DFQO Mat 1].[Material Name] LIKE "*" & [Forms]![DFQO Form 1]![MatNam] & "*"

  )

AND

  (

    Nz([Forms]![DFQO Form 1]![MinFib], -1) = -1

    OR [DFQO Mat 1].[Fibre Content (%)] >= [Forms]![DFQO Form 1]![MinFib]

  )

AND

  (

    Nz([Forms]![DFQO Form 1]![MaxFib], -1) = -1

    OR [DFQO Mat 1].[Fibre Content (%)] <= [Forms]![DFQO Form 1]![MaxFib]

  )

AND

  (

    Nz([Forms]![DFQO Form 1]![MinTenStr], -1) = -1

    OR [DFQO Mat 1].[Tensile Strength (MPa)] >= [Forms]![DFQO Form 1]![MinTenStr]

  )

AND

  (

    Nz([Forms]![DFQO Form 1]![MaxTenStr], -1) = -1
```

```
    OR [DFQO Mat 1].[Tensile Strength (MPa)] <= [Forms]![DFQO Form 1]![MaxTenStr]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MinYouMod], -1) = -1
    OR [DFQO Mat 1].[Young's Modulus (GPa)] >= [Forms]![DFQO Form 1]![MinYouMod]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MaxYouMod], -1) = -1
    OR [DFQO Mat 1].[Young's Modulus (GPa)] <= [Forms]![DFQO Form 1]![MaxYouMod]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MinFleStr], -1) = -1
    OR [DFQO Mat 1].[Flexural Strength (MPa)] >= [Forms]![DFQO Form 1]![MinFleStr]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MaxFleStr], -1) = -1
    OR [DFQO Mat 1].[Flexural Strength (MPa)] <= [Forms]![DFQO Form 1]![MaxFleStr]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MinFleMod], -1) = -1
    OR [DFQO Mat 1].[Flexural Modulus (MPa)] >= [Forms]![DFQO Form 1]![MinFleMod]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MaxFleMod], -1) = -1
```

```
    OR [DFQO Mat 1].[Flexural Modulus (MPa)] <= [Forms]![DFQO Form 1]![MaxFleMod]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MinElo], -1) = -1
    OR [DFQO Mat 1].[Elongation (%)] >= [Forms]![DFQO Form 1]![MinElo]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MaxElo], -1) = -1
    OR [DFQO Mat 1].[Elongation (%)] <= [Forms]![DFQO Form 1]![MaxElo]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MinDen], -1) = -1
    OR [DFQO Mat 1].[Density (kg/m^3)] >= [Forms]![DFQO Form 1]![MinDen]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MaxDen], -1) = -1
    OR [DFQO Mat 1].[Density (kg/m^3)] <= [Forms]![DFQO Form 1]![MaxDen]
  )
AND
  (
    Nz([Forms]![DFQO Form 1]![MinTheCon], -1) = -1
    OR [DFQO Mat 1].[Thermal Conductivity (W/mK)] >= [Forms]![DFQO Form
1]![MinTheCon]
  )
AND
  (
```

Nz([Forms]![DFQO Form 1]![MaxTheCon], -1) = -1

OR [DFQO Mat 1].[Thermal Conductivity (W/mK)] <= [Forms]![DFQO Form 1]![MaxTheCon]

);

This code first takes the necessary items from the database, in other words all of the columns that are used as part of the form. Some, such as material orientation and link to the source from which the material was pulled, are left out of the second part of the query as it is not necessary to filter by them. They are still seen in the first paragraph of the query code, as they still need to be displayed in the output. The chain of triple-line arguments in the second part of the query specifies where the information is entered into the form, and the query then selects the materials that are to be pulled from the database based on those criteria.

The Nz (Number zero) function is used to handle null values, effectively telling the system to ignore the constraint if nothing is entered. The number -1 at the end of the line indicates that Nz is looking out for the user having not entered a value.

The next line afterwards is the expression used if the user enters a value, performing the aforementioned action of comparing the value entered to the database for filtering purposes. In the case of this DFQO system, all of these expressions are <= (less than or equals) or >= (greater than or equals).

The DFQO system's output is the final part, that is visible once the form (or query) is filled out. It takes the same format as the database itself, except filtered based on the form entries. The output can be reset simply by closing it and filling out the form once again with new values or filters.

The following is a description with supporting screenshots from the system, showing how the completed database works, and how the user can navigate the system.

1. Once the database is downloaded onto the user's Microsoft computer, the user can open the DFQO file using MS Access. The file opens on a blank screen with 3 sub headers on the left side of the screen.
2. The user should click "DFQO Form", which then opens the form up. The user is greeted with the form view as seen in Fig. 15. Each of the questions has a box next to it, where

the user can enter their desired value range for each of the specified material properties, as well as the name of the desired material in the top box. Leaving a box empty results in those criteria being excluded from the search.

3. For this example, we will search for: Material Name = Hara (with the aim of finding Harakeke), Maximum Fibre Content % = 40, Minimum Fibre Content % = 30 as can be seen in Fig. 15 below. The remainder of the fields are left blank to show that they will be excluded from the search parameters.
4. Once the user has entered all of their desired values or left the fields empty if they wish to view the whole database, they can click the button as seen in Fig.15 that begins their search.

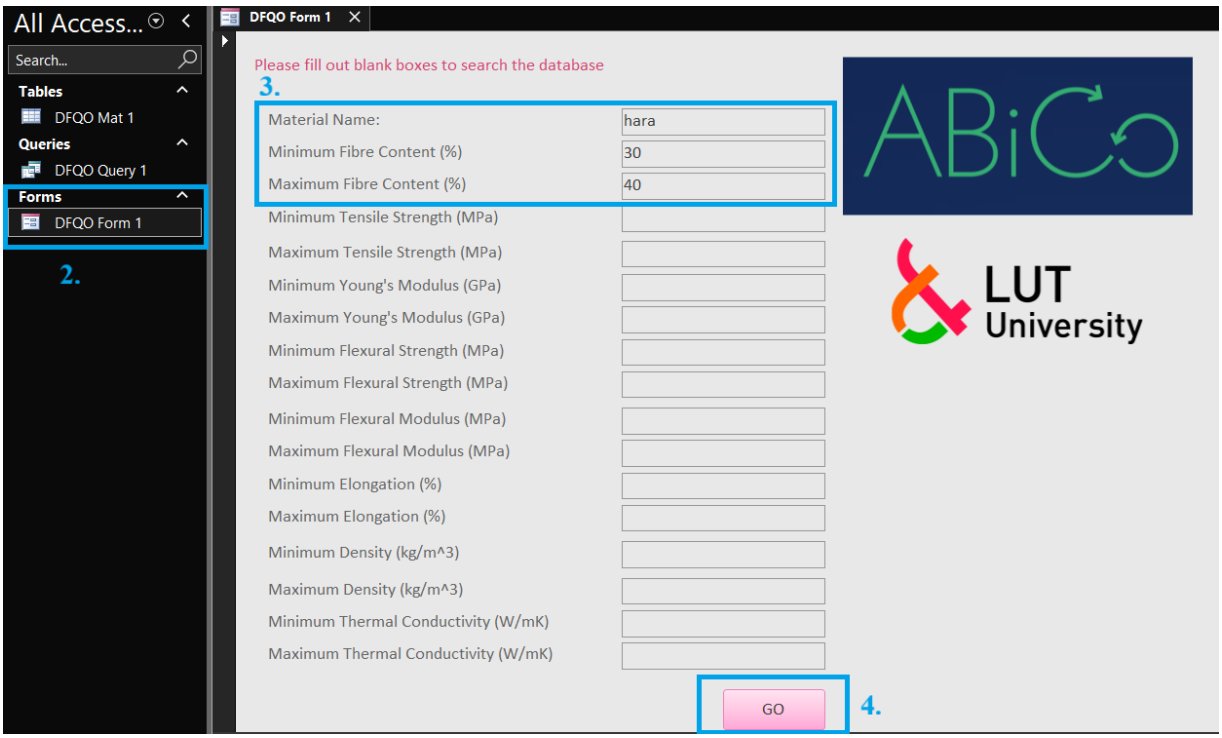

Fig. 15 – Screenshot from the database system showing several steps of utilizing the system. 2 – The location in Access for the user to select the form. 3 – The search criteria for this example. 4 – The GO button used to initialize the search.

5. The user can now view the output. The output in the tool will display all of the results based on the information that the user entered into the form. For example, Fig. 16 below shows the search results based on the criteria: Material Name = Harakeke, Maximum Fibre Content % = 40, Minimum Fibre Content % = 30.

6. Just above the output, the tab showing “DFQO Query” can be seen. Once the user has viewed the output based on their inputs, they can click the “x” to close the tap, at which point they will be returned to the form. They can now restart the process and use the DFQO system all over again.

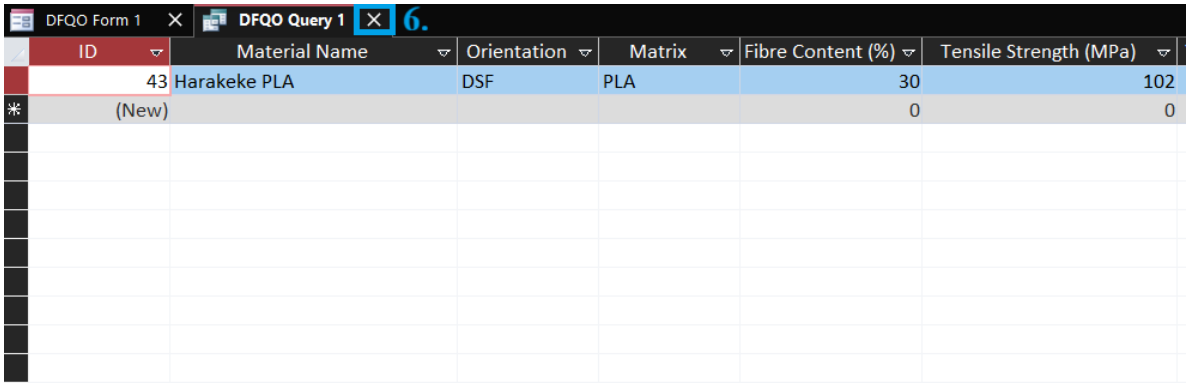

Fig. 16 – Screenshot showing the output from the search criteria, step 6 shows the location to reset the system.

3.2 Instruction Manual

In order to ensure that the user is able to find their way around the DFQO system, an instruction manual was created. The manual contains 3 pages, giving a step by step process for using the DFQO system. The first page requests that for testing purposes, the user first attempts to navigate and use the system unassisted. This is in order to test how intuitive the system is. A simple-to-navigate and intuitive UI is one of the targets for the system and in order to fulfil that goal, the system should be used by anyone.

If the user has trouble navigating the system, then they can use the steps described in the instruction manual to search through the database. The steps cover every action the user would have to perform from start to finish, with diagrams showing the steps when necessary.

The instruction manual can be found in the google drive alongside the database and the feedback form.

Upon completion of the system's design, code and layout, the system was ready for testing and feedback from engineers and researchers within the industry.

3.3 Feedback Form

The feedback from engineers was captured via a google form listing a series of questions. The questions pertained to the DFQO system and its usefulness within the scope of the thesis and to biocomposites. The questions also asked about the potential for the system to be used beyond the scope of this project. The responses were captured with multiple choice values assigned 0-4. 0 representing the lowest value and worst fit (i.e. very unlikely or disagree) and 4 representing the highest value (i.e. very likely or agree). 2 is the neutral value and 1 and 3 are the in-between values. Some other questions had yes/no answers, and the first few were multiple choice questions. The questions posed were the following:

1. What is your field of work?
2. What was/is your educational background?
3. How familiar are you with MS Access?
4. How familiar are you with the SQL language?
5. How familiar are you with biocomposites?
6. How easy was it for you to access this system?
7. How easy was it for you to navigate this system?
8. How intuitive was the layout of the system?
9. Did you need to use the user manual?
10. If you used the user manual, how clear were the instructions in the manual?
11. How well did the system run on your hardware?
12. How satisfied were you with the quantity of materials available in the database?
13. How satisfied were you with the list of material properties provided?
14. How satisfied were you with the system's properties?
15. Would you use the system in an industrial setting?
16. Would you use the system in an educational setting?

17. Do you feel that this system has potential for widespread use with further improvements?
18. Have you used such a system before?

Finally, at the end of the form a box was left for open feedback, which was used for examples behind the quantitative data achieved.

Finally, the DFQO system, the Feedback Form and the Instruction Manual are all kept in the same location, in a Google Drive that can be accessed by anyone with the link. Though it can be accessed, the editing permissions are locked in order to prevent users tampering with the system.

4. Analysis

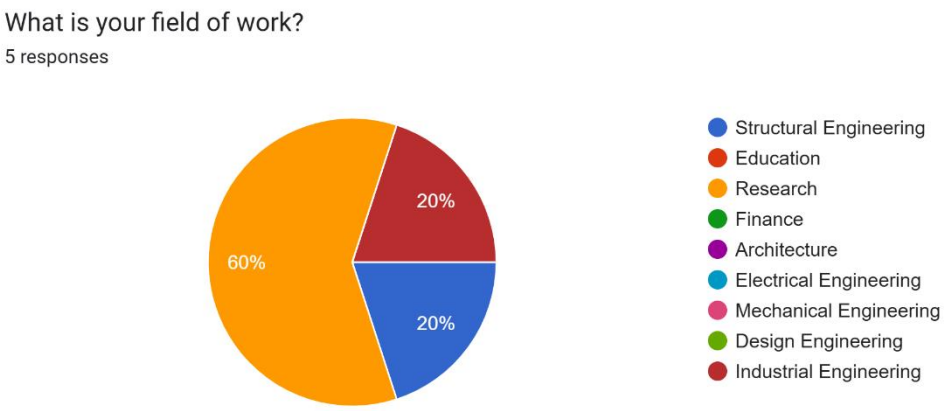

Fig. 17 – "What is your field of work?" Responses.

From this graph we can see that the responders came from 3 different fields of work, but the majority were researchers. The researchers were predominant as expected, due to the feedback for this system mainly coming from the ABiCo group. The varied responses were important for thoroughly testing the system. Perspectives of people with different backgrounds can lead to solutions or questions that gathering information from a single field would not have achieved. For example, the responders of this form came from research, education and structural engineering. This means that 3 will approach this perspective from an academic perspective, another will be able to assess the database's usefulness in an educational setting, and a third can provide valuable insights from an industrial perspective.

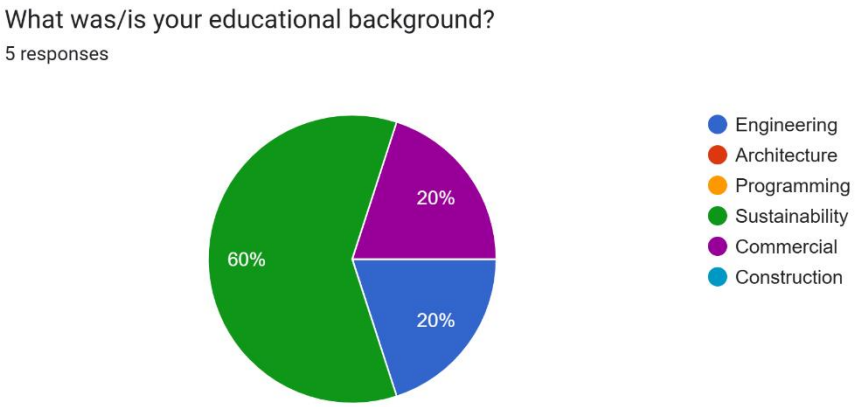

Fig. 18 – "What was/is your educational background?" Responses.

Similarly to the previous graph, people's backgrounds can greatly influenced their perspective of the world, and their insights about the system can be impacted by their education. Those who responded included someone commercially educated, someone with a background in construction and 3 people with a background in sustainability. A variety of responders means that a variety of different perspectives will also be achieved. The focus on sustainability of the ABiCo project meant that several responders came from a background of studies in sustainability, bringing that perspective to the DFQO system's testing.

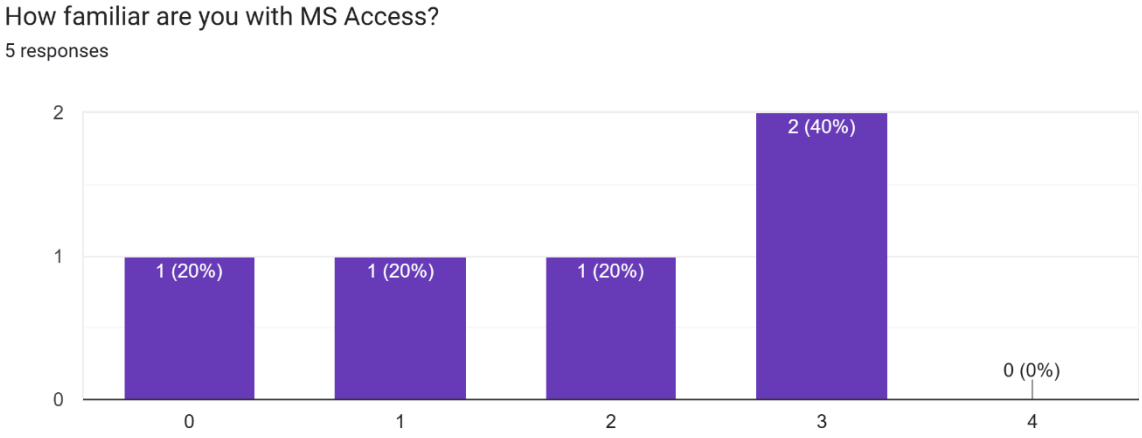

Fig. 19 – "How familiar are you with MS Access?" Responses.

In order to have a better understanding of people's experience testing the system, this question has been asked. It will give a better understanding of the difficulties people will have faced, and how their experience or lack of experience with the application may have impacted their overall perspective. As can be seen from the responses, 2 people were familiar with the application, one answered neutrally, and two were either unfamiliar or very unfamiliar. These responses were also echoed in live presentations of the DFQO system throughout different phases. The room was split in two between people who had questions regarding potential additions to the system and Access' capabilities for those additions, and those who were more interested in the code itself, understanding how the application works.

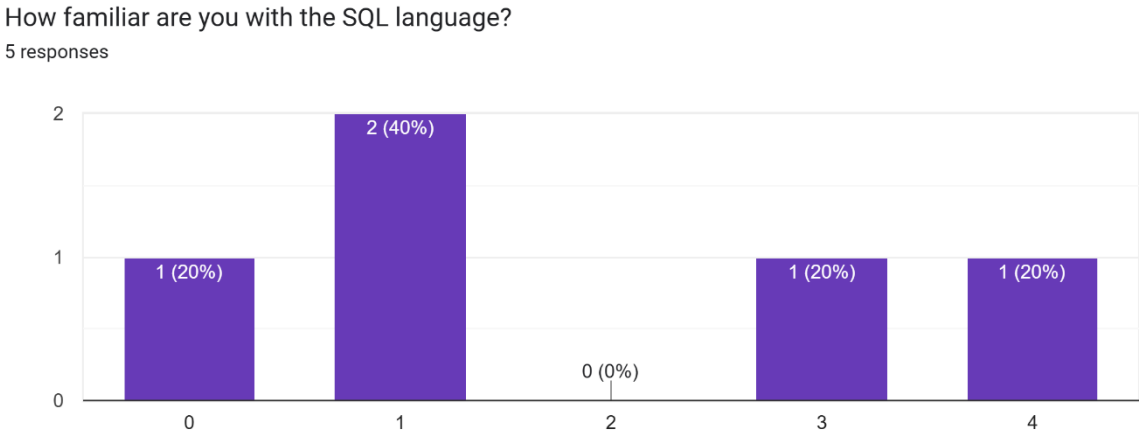

Fig. 20 – "How familiar are you with the SQL language?" Responses.

This question was asked in order to gauge responder's understanding of the foundation that the system was built on. One responder had a very good understanding of the SQL language, one had a good understanding, while two were unfamiliar with it and one was very unfamiliar. As with the previous question, these responses were mirrored in person, with most people being familiar with the likes of Python and JavaScript, some with C++ and R, fewer being familiar with SQL. For this study, it's very useful to have responders who are familiar with SQL, as they gave detailed feedback on the system and its potential for the

future. Some of the comments from responders indicated a desire to switch to a different language of code, as many were unfamiliar with SQL, as can be seen above.

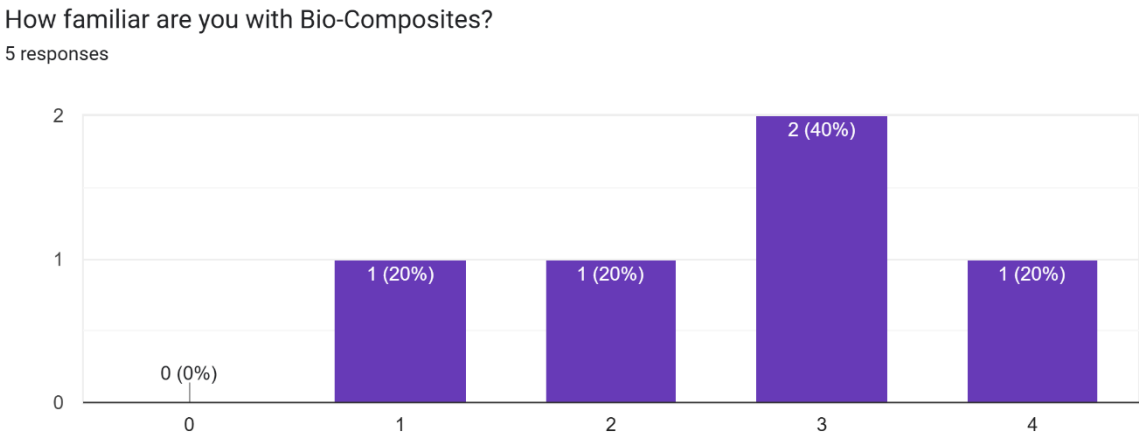

Fig. 21 – “How familiar are you with Bio-Composites?” Responses.

The aim of this question is to establish how many responders are familiar with biocomposite materials. Based on the responses, 1 was very familiar with biocomposites, 2 of the responders are familiar with the material, one responded neutrally and one was unfamiliar. This indicates that on average, responders who are testing the system are able to point out any inconsistencies that may have been overlooked during the system’s population. During a presentation of the system, 1 inconsistency was in fact pointed out, which was then corrected for the system in its current state. The chart being skewed to the right side is a good indicator of people’s knowledge regarding biocomposites.

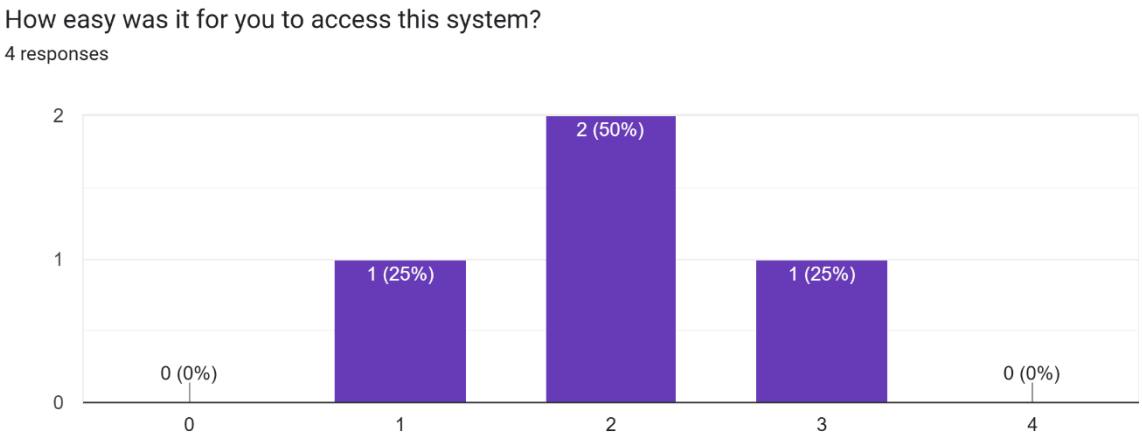

Fig. 22 – "How easy was it for you to access this system?" Responses.

The next set of questions aims to test the usability of the system. One of the responders did not fill out the question, later stating that he was unable to use MS Access on his Macintosh computer. The other four responders chose neutral, easy and difficult as their answers. Further comments from collaborators in person included comments about having to install MS Access. Based on these responses, for further development of the system accessibility will be an important factor. It is an easy system to access, but only if you already have MS Access and thus are on a Microsoft computer. In order to make it more accessible, other software and language options should be explored. Another responder commented at the end that installing MS Access took some time, and that the process might have been more efficient with the implementation of a web-hosted system. In the written responses, another user stated that they needed the manual to access the system and its features properly, but once they did, it was straightforward to use the system.

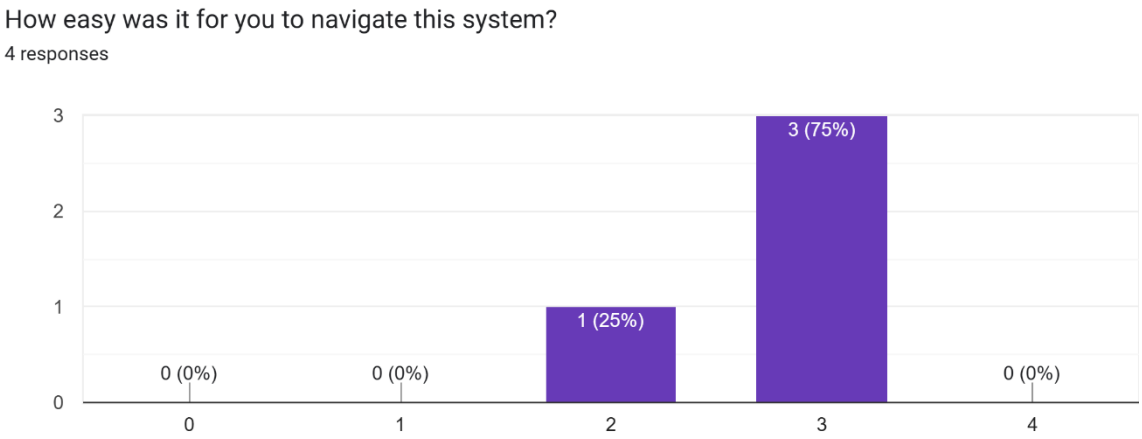

Fig. 23 – “How easy was it for you to navigate this system?” Responses.

Similarly to the previous question, only four responses were captured here. 3 responders selected the option that it was easy to navigate this system, and one responded neutrally. From these responses, and from in-person feedback it can be derived that the system is fairly easy and straightforward to navigate once it has been accessed. In this, one of the goals behind the system’s creation has been achieved. It has a simple layout that is easy to navigate, and the majority of users will have no problem navigating the database once they have access to it. That being said, the chart not being fully skewed to the right implies that the database system could have been even easier to navigate.

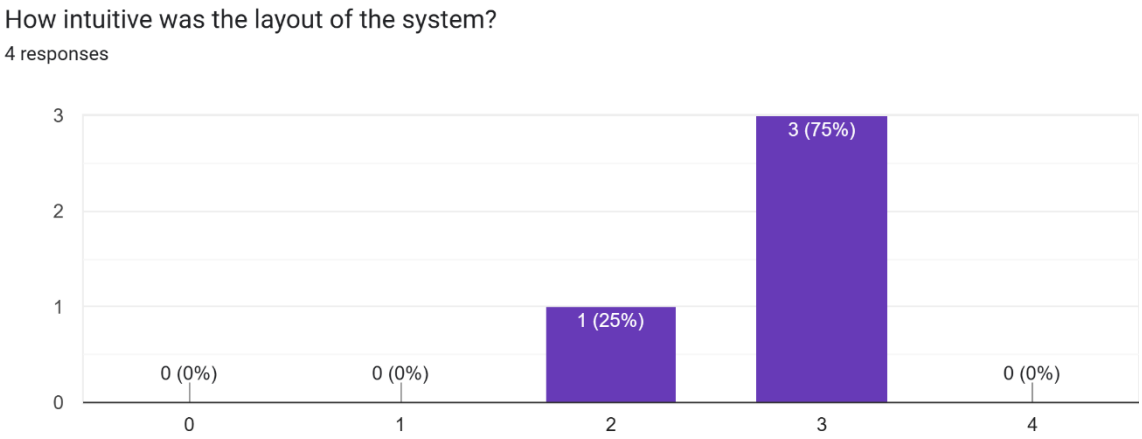

Fig. 24 – “How intuitive was the layout of the system?” Responses.

Same as with the previous question, the graph for this one is skewed to the right, but not all the way. 3 responders found the system to be intuitive, while 1 responded neutrally. There are a few layout quirks within MS Access that come to mind, which may have influenced these responses. Once again, with a pivot to an application or software with more tools and customization options, this could be improved. All of that being said, the responses are positive overall, meaning this target was achieved.

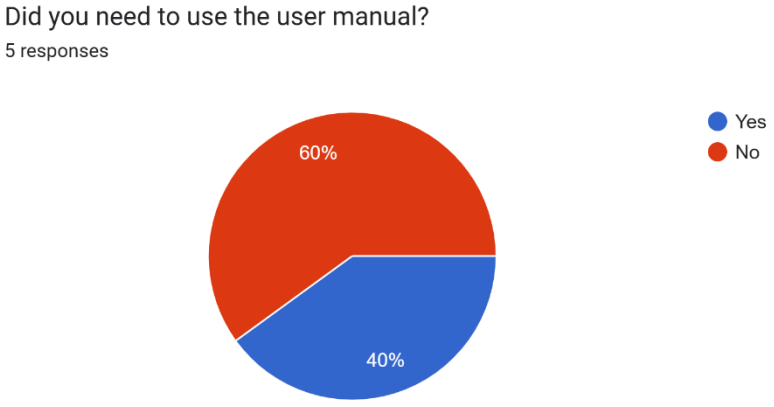

Fig. 25 – “Did you need to use the user manual?” Responses.

Another positive set of responses as three of the five responders did not need to use the user manual to navigate the system. Additionally, one of the responders elaborated that he consulted the manual due to the inability to run the software on a Macintosh computer. Another used the manual to access the system and find the form. The fact that 3/5 users did not require the manual is encouraging, as it shows that the system was intuitive enough to use unimpeded, succeeding in that target. Another used the manual to access the system and find the form.

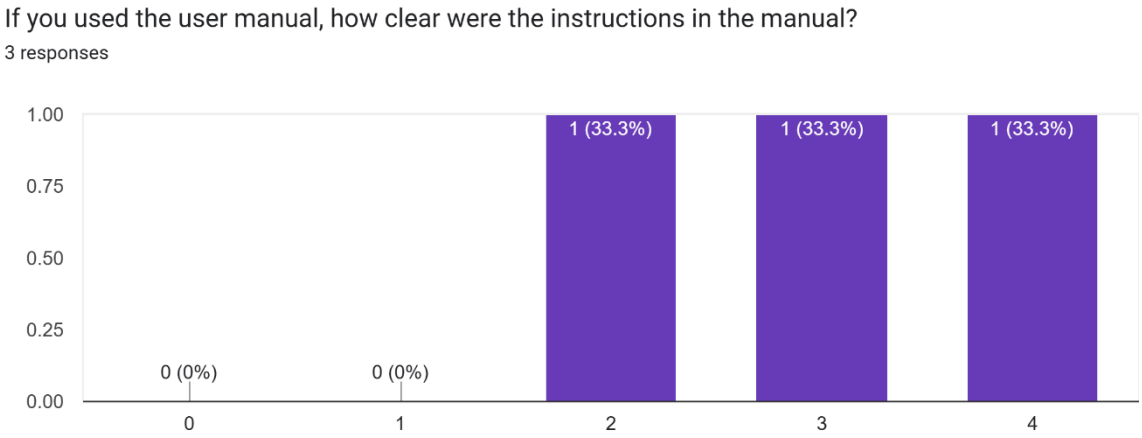

Fig. 26 – "If you used the user manual, how clear were the instructions in the manual?" Responses.

2 responders did not answer this question, likely as they did not need to consult the user manual, and the other three responded neutrally, "clear" and "very clear". This is, once again, skewed to the right indicating that the user manual was easy to follow. That being said, it can be optimised further, with a rework, a tidier layout, and located better. Currently, it is in the same drive as the database system. It could also be incorporated into the system itself, but that would mean the user would need MS Access to view the instructions. Another aspect for consideration in the future of this system's development.

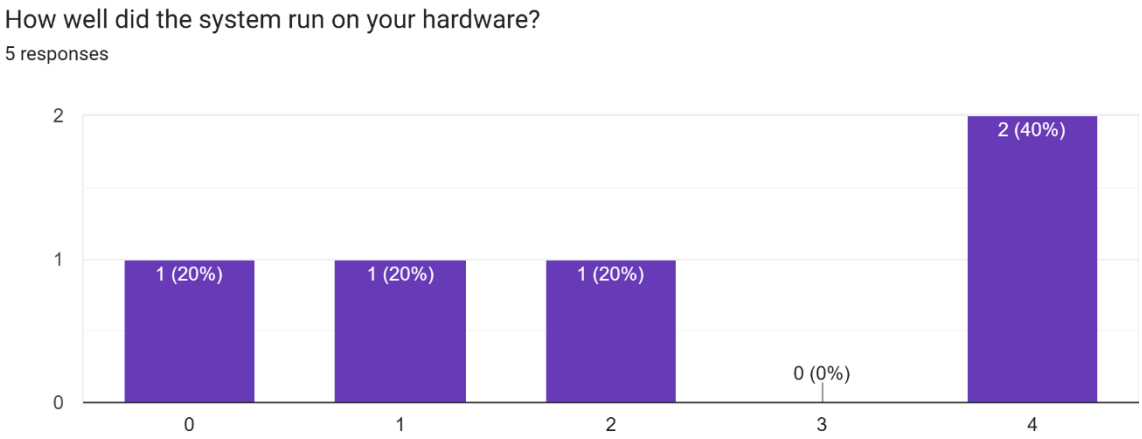

Fig. 27 – “How well did the system run on your hardware?” Responses.

Of all the questions, the responses to this one were the most divided. 1 person responded “very poorly”, 1 responded “poorly”, 1 responded neutrally and 2 responded “very well”. One of the goals for this system was to have a simple system that runs smoothly on just about any hardware. The table being neutral indicates that on average the responders were divided, meaning it didn’t run well on all hardware, but only on some. This is likely due to the software that was used once again. Despite the small file size and relatively simple code, MS Access itself is an application that does not run as well as desired on lower end computers and laptops. This is further motivation to entertain other possibilities in regard to which software will host the DFQO system.

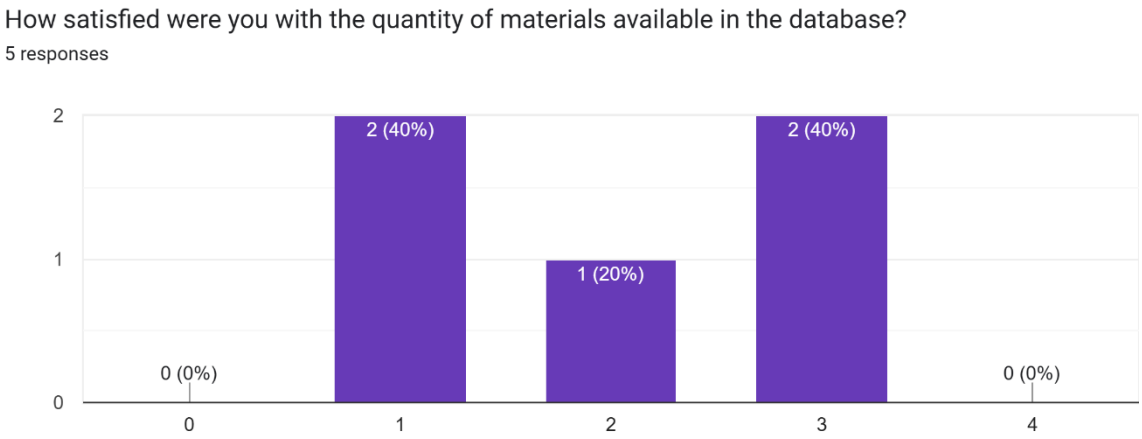

Fig. 28 – "How satisfied were you with the quantity of materials available in the database?" Responses.

Though this was not one of the goals for the DFQO system, in order to establish user satisfaction with the current quantity of materials and set expectations for future development, this question was posed. The responses were divided either side of 1 neutral response, with 2 being somewhat satisfied, and two somewhat unsatisfied. A divisive set of responses as this may be difficult to interpret, however taking an average gives a neutral response. For a prototype of a system, 87 materials were sufficient, but for an industry-ready database there would need to be far more, especially commercially available materials. One of the recurring comments during in-person presentations was regarding a potential way of differentiating between research and commercially available materials, which will be an avenue to explore further in future development of the DFQO system.

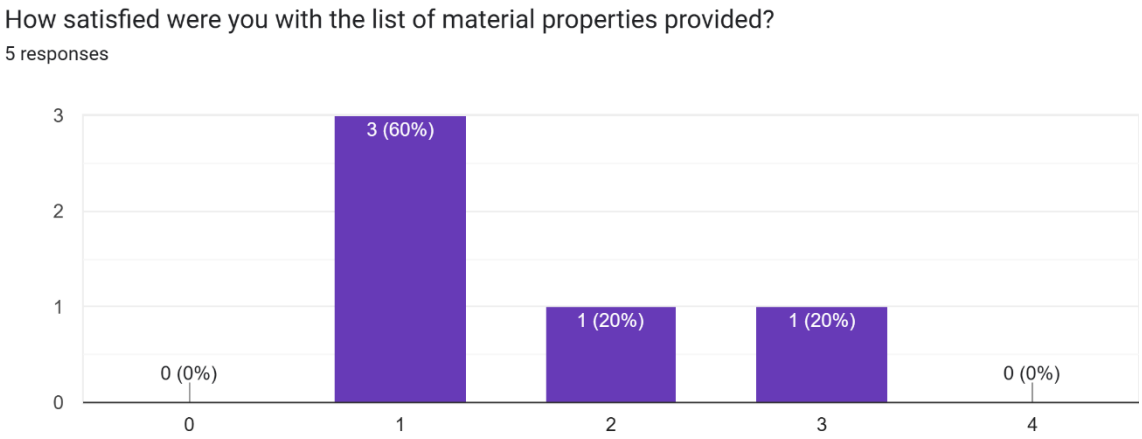

Fig. 29 – "How satisfied were you with the list of material properties provided?" Responses.

In this case, the majority of responders were unsatisfied with the list of material properties provided. 3 responded negatively, 1 responded neutrally and 1 responded positively to the question, indicating overall dissatisfaction. Despite having a wide array of material properties not being a goal for the prototype, it is beneficial to know what the goal will be for the next stages of development. With more commercially available materials being introduced, it is expected that there will also be more properties available to populate in the database. With the current prototype of the database mostly containing research materials, there are many gaps in the property matrix.

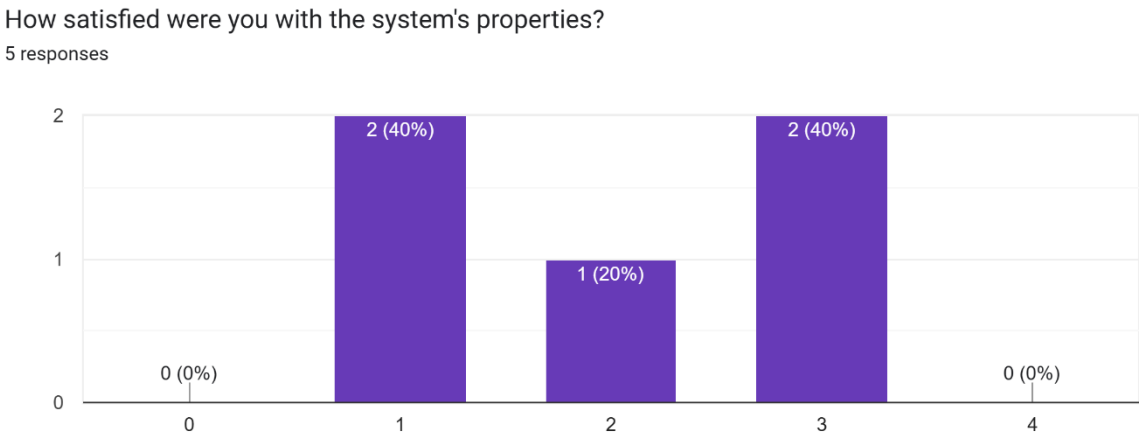

Fig. 30 – "How satisfied were you with the system's properties?" Responses.

The responses to this question were the same as for the previous one, meaning the responders were divided regarding the functions that the system can perform. This is understandable, as the system was designed from scratch to perform two functions quickly, and it thus lacks in depth that other material database systems possess. As a comparison, software such as SolidWorks and ANSYS contain a plethora of materials as well as modelling and simulation functions. The flip side of that is that those have been developed over many years and there is a cost associated with their use. That being said, for the future development of the DFQO system, one of the targets will be the addition of other functions, or potentially even a transition to another platform that can host this database of materials.

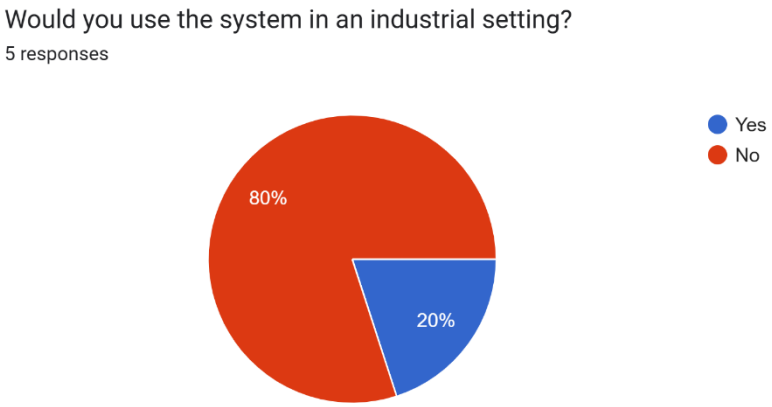

Fig. 31 – "Would you use the system in an industrial setting?" Responses.

The question of the system's application in an industrial setting resulted in 4 "No" responses and 1 "Yes" response. The majority indicates that the system in its current state is likely unfit for use in an industrial setting. This is clear from using the DFQO system, it is a prototype. There would be many additions, refinements, prototypes and additional testing sessions in order for the database to be of an industrial standard, even for a design phase. However, the backbone of the DFQO system has been created and it is proven to work.

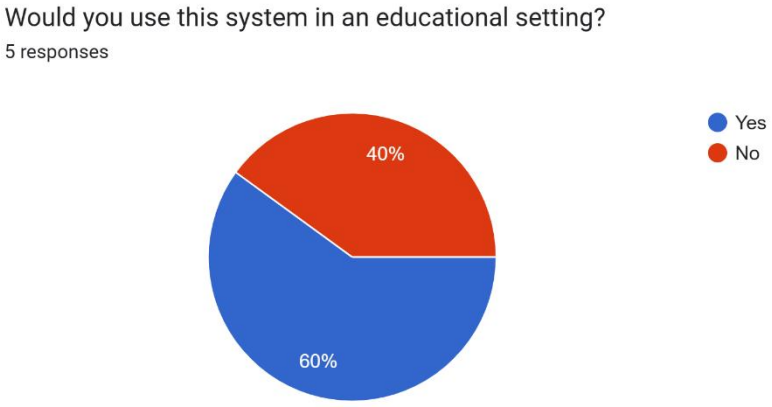

Fig. 32 – "Would you use the system in an educational setting?" Responses.

Unlike the question about using the database in an industrial setting, 3 responders believed the database could be used in an educational setting. This is likely due to the fact that the database can be used as a support tool for engineering, material sciences and sustainability students. Designed to be simple and host 2 main functions with 10 industry materials and 77 research materials, the DFQO system is a good tool for students to use in the design phase of their projects. Beyond that, similarly to the analysis of the previous question, the database lacks a bit of depth. This will be developed further by LUT members in the future.

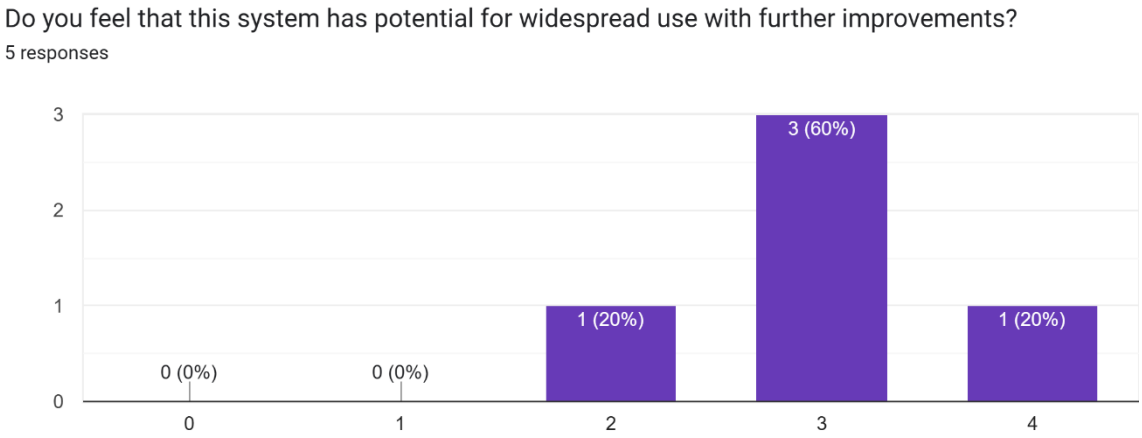

Fig. 33 – "Do you feel that the system has potential for widespread use with further improvements?" Responses.

As can be seen above, the chart of responses to this question is skewed to the right, indicating that users responded positively to the DFQO system's potential. 1 person responded very positively, 3 positively and 1 neutrally to the prospect of the system's potential going forward. This was echoed in live presentations to the ABiCo group, with many people actively participating in the feedback process, both asking questions and stating that they are interested in where the database goes next. It was viewed as a useful tool that can be used to store results of ABiCo's material research into biocomposite materials.

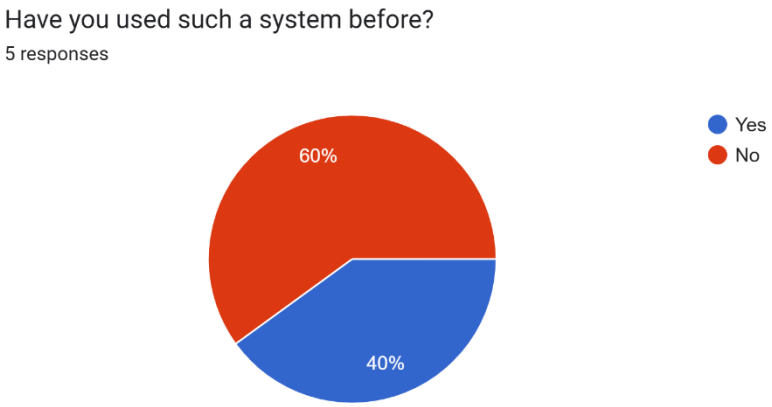

Fig. 34 – "Have you used such a system before?" Responses.

This question has been posed to the responders at the end of the feedback form as a way to gauge their ability to interpret actions within the DFQO system. If they have used similar systems before, it can be beneficial to this one's development to have their opinion. Responders who have used a similar system before may have a perspective that is unique, with valuable insights that may have otherwise been overlooked. It's also a good way to gauge if similar systems have been successful in the past.

In this case, two had used a similar system before, and 3 had not. From informal discussions after the presentation, some ABiCo members mentioned other database systems – such as Aalto's and VTT's construction material databases. Some of these discussions also led to additional research into similar databases, like the EU Commission's database on Bio Industries within the EU.

In order to obtain responses to the form, and to get additional feedback for the final version of the database, the working version of the DFQO system was submitted to members of the ABiCo group towards the end of the thesis work. At the time, it contained 87 materials and 9 material properties. The materials were taken from several scientific literary sources and 10 materials from NG Group. As a result of this, the database was mostly made up of research materials, and only a few commercial options. One of the comments in response to the presentation of the system was to include more

One ABiCo member included a detailed response to the field of the form that is intended for additional comments. This is what was written:

– "*Good start with the demo. I wasn't able to run it on Mac, but I do remember your presentation at the Lahti workshop in June. As you continue, it might be worth moving away from MS Access toward more scalable database setups (there are several good options) with stronger optimization and UI design in mind. I assume you may have chosen Access as a starting point for convenience, but it quickly becomes limiting. Many CAD programs and ERP systems already manage material and cost data in some form. In practice, engineers usually define the specifications in CAD, while procurement handles purchasing separately based on budgets and supplier agreements. Price is rarely a fixed table value—it is more often the result of negotiation or contracts. That is why a separate query system, add-on, or module structure tends to work better than hardcoding prices. For novelty, the real potential could lie in linking your tool into existing CAD/ERP workflows or applying AI/ML to provide smarter matching and optimization. That would make the concept stand out more strongly. Iterating the concept with ChatGPT or similar tools and considering third-party integration questions could be useful—since integration, not standalone offline solutions, is clearly the direction of future development. Feel free to drop me an email if you'd like to discuss further or if you are organizing development workshops. The concept is promising, and I have also been thinking about digital twin applications for Abico, at least at the concept-design level, which could be another project angle. In the Lahti workshop it was mentioned that characterization of a novel material for CAD with full simulation properties can cost around €5,000 per material, so there is a real market opportunity in connecting certified laboratory data with software solutions."*

This feedback echoed previous comments, but included a clearer path for the future of the database. This feedback was not directly implemented into the DFQO system as it was beyond the scope of the thesis, but will be considered for future development of the system.

Another response came after the final presentation of the system:

- *"Still more can be added, more materials and options. Not everyone has Access, so I had to download that which took time. Maybe it can be hosted online somehow. But overall, it can be very useful with some improvements"*

This comment echoed the form responses and in-person feedback, which commented on the functionality and accessibility of MS Access as a platform to host this database.

The final response came just before the completion of the thesis work, after the final feedback meeting. It stated:

- *"I am no material expert so can't really comment on the database content and its usability, but it was fairly easy to open and use. I felt that the manual is needed at least to direct the user to the form."*

The manual being needed is a comment that relates to the intuitive nature of the system. The database could evidently be more intuitive to navigate for some users. Once again, this can

be solved by moving the system to another application or platform. Based on the amount of feedback regarding that aspect of the database, this was identified as the key point for the database system going forward.

5. Discussion

Biocomposite materials are an exciting prospect in the industry of material research. A barrier to wider awareness and research into biocomposite materials is the lack of available information about biocomposites and their mechanical properties. The goal was to create a database system for biocomposite materials that would support engineers in the design phase of a project. The system runs efficiently and performs its tasks to the expected standard. The majority of users who tested the system responded that it ran well and was intuitive, with room for improvement. The accessibility of the system could be better – this was partially due to lack of knowledge about SQL code and the accessibility of MS Access during the system's selection. Though MS Access is an easy SQL platform to get started with, once the complexity of the system increases the software becomes insufficient in its functionality.

To address the research questions that were asked at the beginning of the thesis work:

- How can a materials database tool be created for storing information about and searching for biocomposite materials? – The database was created in MS Access, using SQL code to add search functions to the tool via the query. The database was populated using research biocomposites and commercially available industrial biocomposites. These materials were obtained from scientific literary works and industry partners of LUT. Other materials could have been added to the database but were left out due to confidentiality clauses.
- Can the database system be used in the design phase of engineering projects in educational and industrial applications? – The majority of users responded that the system, in its current state, cannot be used in an industrial setting. This is due to its barebones nature in comparison to other material databases that are present within a system with greater functionality. Over half the users responded that the DFQO tool can be used in an educational setting, for example as a support tool for students researching biocomposites or using biocomposites in research projects in their studies. The majority of users additionally responded that the tool has good potential for wider use industrially with an increase in scope and further development. Conversations internally with the LUT team proposed moving the system to another platform in order to improve functionality and accessibility.

- Can the database system increase awareness and improve accessibility of biocomposite materials and their mechanical properties? – Feedback received from the ABiCo group was positive in regard to the DFQO system's potential to increase awareness of biocomposites and improve their accessibility. ABiCo participants expressed excitement at the prospect of such a database existing from the get go, both as a way of storing the mechanical property results from their research into the materials, and as a way to increase the reach of the research by making the database widely available. One of the responders, for example, mentioned they were not a materials expert despite participating in the ABiCo project, and their understanding of biocomposites was likely impacted in a positive manner by testing the DFQO system. For those in a similar position, this tool can be a useful way to get a better understanding of the different materials, properties and what impacts the properties of those specific materials.

Overall, the DFQO system and its contribution to the ABiCo project can be classed as a success. Based on the quantitative data obtained, it can be inferred that the final system is one that is simple and easy to use, clear with its content and fast. It allows designers and manufacturers to access material properties for a wide variety of biocomposites and advanced composites as it was set out to do. The responders, who were mostly researchers with a background in sustainability were able to advise as to potential improvements with the system and to reduce any shortcomings throughout its inception.

The system, in its current state, can be published online for people to openly download and use. Although the system is still in a prototype phase, users having access to it and to any future updates would allow them to have access to an increasing quantity of biocomposite materials and their mechanical properties. From background research, this is the first system for biocomposite materials with additional functionality beyond just information storage. The search and filter functions that were created using the DFQO system set it apart from other databases. It also performs the standard function of information storage and can be used for just that.

While the creation of a biocomposite materials database was a success overall, it's important to note down the limitations that were encountered during its creation. Firstly, it was the small scope of the thesis that was constrained to a single person with limited support from a

team of researchers. The ideation behind the database was mostly an individual process, therefore there was also a limit on the potential of the system for the first completed prototype. The limited funding meant that some tools were not available for testing. MS Access was chosen as the best option, but with additional funding, time and staff other options could have been explored. Background research was limited to open scientific literary sources and sources available through LUT. And finally, the functionality of the system was largely dependent on the one person coding it, who had a limited understanding of languages such as SQL, JavaScript, Python, C++ and R. With more time to study the languages and to understand how they work, more functionality and depth could have been added to the database system.

For future development of the system, there are several directions that could be taken. Based on feedback, the main improvement should be an improvement in accessibility of the system. Some users with Macintosh computers and others with no access to MS Office applications were unable to access this system. The database being located more openly would greatly benefit the users' ability to access it and thus would increase the visibility of biocomposite materials within engineering and material selection. An example of a database that is optimised in this way is the EU Commission's database of Bio-Based Industries. The database is hosted on the EU Commission's website, making it openly available to all with an internet connection. It's visible as the page opens up, and from the simplified layout it is also easy to navigate and use.

Another direction of additional research is that of volume of information. Currently, the database contains 87 materials and 9 mechanical material properties. To bolster the database, more commercially available materials could be added to it. With only 10 commercially available materials being in the current version of the database, this prototype is severely lacking in terms of its potential for industrial use. One aspect discussed with researchers was the potential to create 2 similar databases, running off the same code. One of them would contain research materials only, and the other would contain exclusively commercially available materials. As well as biocomposite materials, adding more material properties, even if there will be spaces within the database matrix due to all of the properties not being obtainable for every material, would also improve the functionality of the database system. Having more material properties would mean that it would be relevant to a wider field of applications.

A final suggestion on future research pertains to legacy versions of the database. As the database is updated with newer materials, and newer versions of materials, some material properties will change over time. For example, 10 years ago a certain material may have lacked in tensile strength and through development that material's tensile performance was improved. The updated version of the database would show the improved tensile strength. The idea behind the legacy versions of the database would be to have all of the previous versions of the database publicly available, stored separately from the main database. That way those who are curious about the history and development of biocomposite materials through the years could proverbially go back in time and see how far biocomposite materials have come in that time. It would add minimal functionality to the database itself, but it would be a good reference point to show the development of this field.

The DFQO system's contribution to the field currently lies mostly within the scope of the ABiCo project. The database can serve as the main storage of material properties obtained as a result of biocomposite material development and testing by VTT, LAB and UEF. It can also benefit NG Nordic by increasing the awareness of their biocomposite products. The database is one of the first of its kind, and the first of its kind with the designed functions for biocomposite materials. The selection of filter functions sets it apart from other databases, and this aspect, if implemented into other databases could greatly improve their functionality.

6. Conclusion

With composite materials increasingly being utilised within various fields of engineering and design, the question of their sustainability has arisen due to a lack of end-of-life options. In recent years, biocomposite materials have been identified as a potentially more sustainable alternative to traditional composite materials. As the research into biocomposites is at an early stage, many people will not consider them as an option when selecting materials due to a lack of awareness and accessibility. The DFQO database tool provides a platform for the storage and circulation of information about these innovative materials, with the aim of increasing engineers' visibility of biocomposites. The system was created from scratch within the Microsoft platform, on the Microsoft Access application. This was due to its functionality being suited to database creation, utilizing the SQL coding language and by providing a user-friendly and intuitive platform. The completed DFQO tool is fast, intuitive and functional, lending to its research and industrial usability. The tool is still at an early stage, with plenty of options for future research and development, such as the implementation of the system on a different platform, the addition of more commercially available materials from within the industry and the publicly available storage of previous versions of the system to track biocomposite material development. The DFQO system has the potential to make information regarding biocomposite materials, and their mechanical properties more available to engineers within the industry and the general public alike. With increased visibility of, and thus increased use of biocomposite materials, the population of Planet Earth can begin to phase out materials that take up space on landfills, pollute their environment and negatively impact the health of people.

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Database Contents

DFQO Mat 1

ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
2	S-ACC Spinnova ACC	35	13							https://www.mdpi.com/2073-4360/15/3/475		
3	L-ACC Lyocell ACC	43	36							https://www.mdpi.com/2073-4360/15/3/475		
4	S-BC2 Spinnova thin	33	16							https://www.mdpi.com/2073-4360/15/3/475		
5	L-BC2 Lyocell thin	50	20							https://www.mdpi.com/2073-4360/15/3/475		
6	S-BC4 Spinnova thick	37	14							https://www.mdpi.com/2073-4360/15/3/475		
7	L-BC4 Lyocell thick	51	21							https://www.mdpi.com/2073-4360/15/3/475		
8	Hay 50	6		Random	Rosin	50	0	6		https://www.mdpi.com/2071-1050/9/3/373		
9	Hay 70	13		Random	Rosin	70	1	6		https://www.mdpi.com/2071-1050/9/3/373		
10	Alfa	149		Aligned	UP	48	12			https://www.mdpi.com/2071-1050/9/3/373		

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ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
11	Cellulose	92		Continuous	Bio-Epoxy		9	727	27000	https://www.mdpi.com/2071-1050/9/3/373		
12	Cordenka PA	120			PA	30	6			https://www.mdpi.com/2071-1050/9/3/373		
13	Cordenka PP	90			PP	42	4			https://www.mdpi.com/2071-1050/9/3/373		
14	Cordenka PLA	108			PLA	25	4			https://www.mdpi.com/2071-1050/9/3/373		
15	Flax PP 30	52			PP	30	5	60		https://www.mdpi.com/2071-1050/9/3/373		
16	Flax Epoxy 46	280		Aligned	Epoxy	46	35	223		https://www.mdpi.com/2071-1050/9/3/373		
17	Flax Epoxy 54	279		Aligned	Epoxy	54	39	223		https://www.mdpi.com/2071-1050/9/3/373		
18	Flax Epoxy 37	132		Aligned	Epoxy	37	15			https://www.mdpi.com/2071-1050/9/3/373		
19	Flax PP 50	40		Aligned	PP	50	7			https://www.mdpi.com/2071-1050/9/3/373		
20	Flax PP 39			Aligned	PP			212	23000	https://www.mdpi.com/2071-1050/9/3/373		
21	Flax UP 39	61		Random	UP	39	6	91	5000	https://www.mdpi.com/2071-1050/9/3/373		

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ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
22	Flax PLA 30	100		Random	PLA	30	8			https://www.mdpi.com/2071-1050/9/3/373		
23	Flax PLLA 30	99		Random	PLLA	30	9			https://www.mdpi.com/2071-1050/9/3/373		
24	Flax Shellac 49	109		Short-nonwoven	Shellac	49	10			https://www.mdpi.com/2071-1050/9/3/373		
25	Flax Epoxy 50	104		Woven	Epoxy	50	10			https://www.mdpi.com/2071-1050/9/3/373		
26	Flax Hackled			Aligned	Epoxy	28		182	20000	https://www.mdpi.com/2071-1050/9/3/373		
27	Flax Silver UP	304		Aligned	UP	58	30			https://www.mdpi.com/2071-1050/9/3/373		
28	Flax Silver PP			Aligned	PP	44		146	15000	https://www.mdpi.com/2071-1050/9/3/373		
29	Flax Silver Epoxy	200		Biaxial/Major	Epoxy	46	17	194	13000	https://www.mdpi.com/2071-1050/9/3/373		
30	Flax Yarn Epoxy 45			Aligned	Epoxy	45		311	25000	https://www.mdpi.com/2071-1050/9/3/373		
31	Flax Yarn Epoxy 31	160		Aligned	Epoxy	31	15	190	15000	https://www.mdpi.com/2071-1050/9/3/373		
32	Flax Yarn Epoxy 44.9	133		Aligned	Epoxy	45	28	218	18000	https://www.mdpi.com/2071-1050/9/3/373		

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ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
33	Flax Yarn VE 24	248		Aligned	VE	24	24			https://www.mdpi.com/2071-1050/9/3/373		
34	Flax Yarn UP	143		Aligned	UP	34	14	198	17000	https://www.mdpi.com/2071-1050/9/3/373		
35	Flax Yarn PP 72	321		Aligned	PP	72	29			https://www.mdpi.com/2071-1050/9/3/373		
36	Flax Yarn PP 30	89		Aligned	PP	30	7			https://www.mdpi.com/2071-1050/9/3/373		
37	Flax Yarn PP 29.9	70		Aligned	PP	30	6			https://www.mdpi.com/2071-1050/9/3/373		
38	Flax Yarn VE 35	111		Woven	VE	35	10	128	10000	https://www.mdpi.com/2071-1050/9/3/373		
39	Harakeke Epoxy 50	223		Aligned	Epoxy	50	17		14000	https://www.mdpi.com/2071-1050/9/3/373		
40	Harakeke Epoxy 55	223		Aligned	Epoxy	55	17		14000	https://www.mdpi.com/2071-1050/9/3/373		
41	Harakeke Epoxy 52	211		Aligned	Epoxy	52	15			https://www.mdpi.com/2071-1050/9/3/373		
42	Harakeke Epoxy 45	136		DSF	Epoxy	45	11	155	10000	https://www.mdpi.com/2071-1050/9/3/373		
43	Harakeke PLA	102		DSF	PLA	30	8			https://www.mdpi.com/2071-1050/9/3/373		

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ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
44	Harareke Epoxy 44.9			Random	Epoxy	45		188	9000	https://www.mdpi.com/2071-1050/9/3/373		
45	Hemp PP 40	52			PP	40	4	86	4000	https://www.mdpi.com/2071-1050/9/3/373		
46	Hemp Epoxy 65	165		Aligned	Epoxy	65	17	180	9000	https://www.mdpi.com/2071-1050/9/3/373		
47	Hemp PP 46			Aligned	PP	46		127	11000	https://www.mdpi.com/2071-1050/9/3/373		
48	Hemp PLA 30	77		Aligned	PLA	30	10	101	7000	https://www.mdpi.com/2071-1050/9/3/373		
49	Hemp PLA 45	62		Biaxial	PLA	45	7	124	9000	https://www.mdpi.com/2071-1050/9/3/373		
50	Hemp PLA 29.9	83		Carded	PLA	45	11	143	7000	https://www.mdpi.com/2071-1050/9/3/373		
51	Hemp Epoxy 50	105		DSF	Epoxy	50	9	126	8000	https://www.mdpi.com/2071-1050/9/3/373		
52	Hemp Epoxy 64.9	113		DSF	Epoxy	65	18	145	10000	https://www.mdpi.com/2071-1050/9/3/373		
53	Hemp PLA 25	87		DSF	PLA	25	9			https://www.mdpi.com/2071-1050/9/3/373		
54	Hemp PLA 47	55		Random	PLA	47	9	113		https://www.mdpi.com/2071-1050/9/3/373		

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ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
55	Jute PP	74			PP	60	11	112	12000	https://www.mdpi.com/2071-1050/9/3/373		
56	Jute UP	50		Woven	UP	35	8	103	7000	https://www.mdpi.com/2071-1050/9/3/373		
57	Kenaf PLA 40	82		Aligned	PLA	40	8	126	7000	https://www.mdpi.com/2071-1050/9/3/373		
58	Kenaf PHB	70		Aligned	PHB	40	6	101	7000	https://www.mdpi.com/2071-1050/9/3/373		
59	Kenaf PP	46		Random	PP	30	5	58	4000	https://www.mdpi.com/2071-1050/9/3/373		
60	Kenaf PLA 80	223		Aligned	PLA	80	23	254	22000	https://www.mdpi.com/2071-1050/9/3/373		
61	Kraft PP	52			PP	40	3	90	4000	https://www.mdpi.com/2071-1050/9/3/373		
62	Lyocell PLA	89		Carded	PLA	30	9	148	6000	https://www.mdpi.com/2071-1050/9/3/373		
63	Lyocell PHB	66		Carded	PHB	30	5	105	5000	https://www.mdpi.com/2071-1050/9/3/373		
64	Newsprint	53			PP	40	3	94	4000	https://www.mdpi.com/2071-1050/9/3/373		
65	PALF	53		Random	UP	30	2	80	3000	https://www.mdpi.com/2071-1050/9/3/373		

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ID	Material Name	Tensile Strength (MPa)	Elongation %	Orientation	Matrix	Fibre Content (%)	Young's Modulus (GPa)	Flexural Strength (MPa)	Flexural Modulus (MPa)	Link	Density (kg/m^3)	Thermal Conductivity (W/mK)
66	Sisal 73	410		Aligned	Epoxy	73	6	320	27000	https://www.mdpi.com/2071-1050/9/3/373		
67	Sisal 77	330		Aligned	Epoxy	77	10	290	22000	https://www.mdpi.com/2071-1050/9/3/373		
68	Sisal 48	211		Aligned	Epoxy	48	20			https://www.mdpi.com/2071-1050/9/3/373		
69	Sisal 37	183		Aligned	Epoxy	37	15			https://www.mdpi.com/2071-1050/9/3/373		
70	Wood BKP	50			PP	40	3	78	3000	https://www.mdpi.com/2071-1050/9/3/373		
71	Hay Rosin 50			Random	Rosin	50	0	6		https://www.mdpi.com/2071-1050/9/3/373	989	0
72	Hay Rosin 60			Random	Rosin	60	1	11		https://www.mdpi.com/2071-1050/9/3/373	934	0
73	Hay Rosin 70			Random	Rosin	70	1	13		https://www.mdpi.com/2071-1050/9/3/373	791	0
74	Manchurian Ash (MA)	63	25	Random	BMIMCI					https://www.mdpi.com/2073-4360/12/2/361		
75	MA 5	195	12	Random	BMIMCI					https://www.mdpi.com/2073-4360/12/2/361		
76	MA 10	213	7	Random	BMIMCI					https://www.mdpi.com/2073-4360/12/2/361		

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77	MA 15	75	4	Random	BMIMCI					https://www.mdpi.com/2073-4360/12/2/361		
78	Circo PP-CF 40	47				40		77	3800	https://www.ngnordic.com/fi	1050	
79	Circo PP-CF 30	39				30		67	3300	https://www.ngnordic.com/fi	1030	
80	Circo PP-CF 20	30				20		51	2300	https://www.ngnordic.com/fi	990	
81	Circo PP-CF 10	24				10		38	1600	https://www.ngnordic.com/fi	950	
82	Circo PP-CF 40 HF	44				40		79	4300	https://www.ngnordic.com/fi	1090	
83	Circo PP-CF 30 HF	37				30		64	3100	https://www.ngnordic.com/fi	1040	
84	Circo PP-CF 20 HF	31				20		51	2300	https://www.ngnordic.com/fi	1000	
85	Circo PP-CF 30-Hfi-4031	31				30		53	2800	https://www.ngnordic.com/fi	1040	
86	Circo PP-CF 20 Hfi-5516	26				20		43	1900	https://www.ngnordic.com/fi	990	
87	Circo PP-CF 20-HB-4015B	31				20		50	2400	https://www.ngnordic.com/fi	1060	